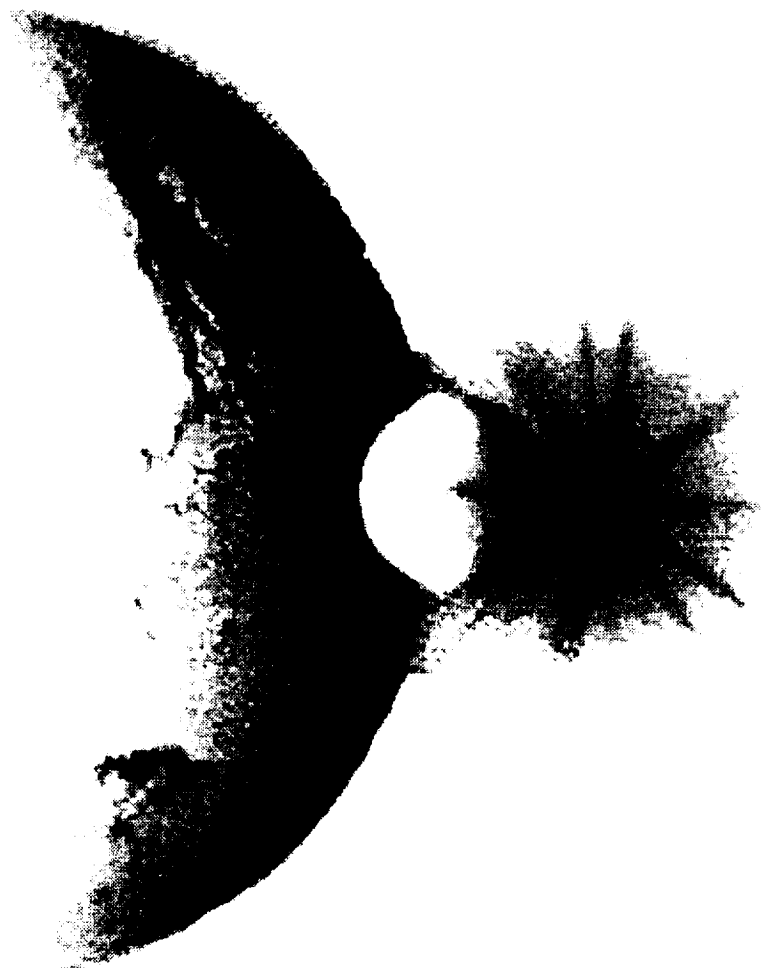
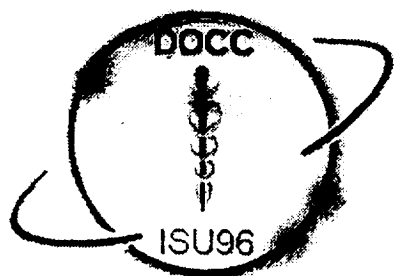




Distant Operational Care Center

Design Project Report



primum non nocere

(first, do no harm)

-attributed to Hippocrates

To Mother Teresa
and Arthur C. Clarke

*May their dedication, caring, and vision
ensure the safe spread of humankind
as we take our first steps into the Universe.*

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Student Preface

The DOCC report is the product of one of the group design projects of the International Space University (ISU) 1996 Summer Session Program, hosted by the Technical University of Vienna, Austria. During the ten weeks of the session, the group project has been one of the major activities of the course, and has drawn together the 51 team members, from 23 countries and 5 continents, to work as a single integral team. The multi-cultural and multi-disciplinary background of the students covered topics from medicine, engineering, business, policy and science and together through much discussion, reasoning and debate we have derived the DOCC.

The space environment presents many hazards for humans. Whether it be the harsh thermal environment, intense radiation exposure or physiological changes brought about due to microgravity, if people are to continue to explore the Universe and proceed to exploit its bounty of resources, a medical facility able to promote the good health of the astronauts is essential. DOCC presents the initial findings into the first such study. Starting with the concept of a modular medical facility and developing it into a core unit, plus a range of additional elements which may be required to support particular environments, a design solution is offered for further future study. The report additionally considers novel business, management, political and commercial aspects which may be applied for the implementation of such a facility.

Whilst the report becomes the major output of the project equally important are the aspects which are more difficult to express, but which all of the students involved in the project experience at first hand. Firstly there is the team working, not in a small team of fellow country folk, but in a large international team. The different work practices of the represented countries and cultures are highlighted, and adaptation and understanding grow. Time management ability also becomes important as between the lectures, workshops and seminars, meetings and group team activities have to be accommodated. Negotiation and reasoning skills are additionally strengthened as each team member tries to ensure the recognition and prominence of their input. Finally, decision making and the ability to work to strict deadlines whilst under pressure are further important lessons learned.

The time at ISU and the ten weeks spent conducting the DOCC study have truly been influential for the 51 students involved, but the DOCC does not finish with the end of the summer session. The need for a DOCC type facility in the near future is obvious and whatever form the flight hardware takes, we sincerely hope that one day the results of this study will be helping to promote and maintain the health of the brave few who venture into space.

Faculty Preface

The International Space University (ISU) Summer Session is a program in space studies at the graduate school level. One of the several major program components is the Design Project. The design project is a group research activity. The projects are intended to promote two of the goals of ISU: interdisciplinary and international collaboration. For many students, an ISU design project is their first educational experience in working in a large collaborative group activity. The ISU process includes engineering, life science, space science, architecture, management, legal and policy experts. Each design project is an examination of and discussion about advanced space activities. The design project topic is carefully chosen to force discussion and co-operation between interdisciplinary groups.

The ISU 1996 Summer Session Program featured two design projects: one about solar exploration and the other about space medicine care. In both projects students used information about past research in the related field as well as the current state of the art, but starting from this base line they dealt with the future of space exploration.

Fifty-one students of the 104 members in the ISU class of 1996 chose to work on the exciting theme of a remote integrated medical facility later named by the students Distant Operational Care Centre (DOCC). Medical care has been a component of manned space flight since its beginning, however, there has not been a group that has dedicated itself to medical issues of missions beyond the current era. DOCC is intended to address some of these issues in a comprehensive manner.

There are two major outflows of a design project and one is in your hands: the report, a product of interdisciplinary work and research activity of an international group of students with different educational and professional backgrounds. This product has begun the discussion of future medical issues in space flight. Questions as diverse as how hardware will be financed and how technological advances will be incorporated are addressed here.

The other outflow of a design project cannot be touched by hands but is nevertheless of great importance. It is the personal experience of the design project process. This includes: integration and co-operation, group interaction in small and large groups, setting of a decision and communication structure, preparing and making decisions and information distribution and control. The DOCC design project team managed this process on their own. Faculty members of this process valuable experience has been gained. However, most important, through completing this design project and the summer session, this group has joined the hundreds of alumni of the ISU experience.

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Table of Contents

Table of Contents	I
List of Figures	XIII
List of Tables	XV
Acronyms	XVII
Executive Summary	XXI

INTRODUCTION

Calling for a DOCC.....	1
A Dangerous Place	1
A Future Frontier.....	2
For the Millions.....	2
Higher, Bigger, Longer	3
A Need for a Core Medical Capability.....	3
Mission Statement.....	4
Design Approach.....	4
Formulate Medical Requirements.....	4
Design Core Module.....	5
Adapt Core Case to Applications	5
Identify Business and Legal Issues and Analyse Policy.....	7
Conclusions.....	7

SECTION I: MEDICAL REQUIREMENTS

CHAPTER 1: Assessment of Medical Events

1.1 Introduction.....	11
1.2 Medical Events	13
1.3 Crew Selection.....	19
1.3.1 Introduction.....	19
1.3.2 Medical Selection	19
1.3.3 Psychological Crew Selection	21
1.3.3.1 Psychiatric Selection Criteria	22
1.3.3.2 Psychological Selection Criteria.....	22
1.3.3.3 Psychosocial Selection Criteria	22
1.3.3.4 Unit of Selection.....	22
1.3.3.5 Conclusions.....	23
1.4 Crew Psychological Support System (CPSS).....	23
1.4.1 Introduction.....	23

1.4.2	The Space Flight Environment.....	24
1.4.3	Stressors in the Space Flight Environment.....	25
1.4.3.1	Physiological and Physical Stressors.....	25
1.4.3.2	Psychological Stressors	26
1.4.3.3	Psychosocial Stressors.....	26
1.4.4	Space Analogue Environments.....	27
1.4.5	Effects of Space and Space-Analogue Environments	28
1.4.5.1	Somatic Effects.....	28
1.4.5.2	Psychological Effects.....	28
1.4.5.3	Psychosocial Effects	29
1.4.5.4	Cognitive Effects	30
1.4.5.5	Psychiatric Effects	30
1.4.6	CPSS System Description	30
1.4.6.1	Liveware	31
1.4.6.2	Hardware.....	32
1.4.6.3	Software.....	32
1.4.6.4	Research Platform.....	33
1.4.6.5	Psychological Countermeasures Training	33
1.4.7	Habitability	35
1.4.8	Conclusions.....	36
1.5	Habitability Conditions.....	36
1.5.1	Sleep	37
1.5.2	Clothing	37
1.5.3	Personal Hygiene.....	38
1.5.4	Food Preparation.....	38
1.5.5	Habitat Aesthetics.....	39
1.5.6	Outside Communications.....	39
1.5.7	Recreational Opportunities.....	39
1.5.8	Privacy and Personal Space.....	40
1.5.9	Behavioural Requirements Associated with a Microgravity Environment	41
1.5.10	Temperature.....	41
1.5.11	Lighting.....	41
1.5.12	Noise.....	41
1.6	Physiological Deconditioning Due To Microgravity Exposure and Recommended Countermeasure	42
1.6.1	Introduction.....	42
1.6.2	Cardiovascular Deconditioning.....	42
1.6.2.1	Orthostatic Hypotension	42
1.6.2.2	Decrease in Work Capacity	43
1.6.2.3	Cardiac Rhythm Disorders	44
1.6.3	Cardiovascular Deconditioning Countermeasures	44
1.6.3.1	Decreased Plasma Volume	44
1.6.3.2	Impaired Muscle-Venous Interaction	45
1.6.3.3	Decreased Interstitial Fluid around Leg Veins	45
1.6.3.4	Increased Venous Distensibility	45
1.6.3.5	Impaired Arterial Vasoconstriction	45

1.6.3.6	Impaired Heart Function.....	45
1.6.3.7	Attenuated Arterial Baroreflex Sensitivity	46
1.6.3.8	Attenuated Cardiopulmonary Baroreflex Sensitivity	46
1.6.3.9	Reduced Work Capacity	46
1.6.4	Deconditioning of the Skeletal System.....	46
1.6.5	Skeletal System Countermeasures.....	48
1.6.6	Deconditioning of the Muscular System	48
1.6.7	Muscular System Countermeasures.....	49
1.6.8	Neurosensory and Sensory Motor Functions Deconditioning.....	50
1.6.9	Neurosensory Countermeasures	51
1.6.10	Immune System Changes	51
1.6.11	Immune System Changes Countermeasures.....	52
1.6.12	Exercise Prescription	52
1.7	Pharmaceutical Requirements	53
1.8	Dental Kit.....	54
1.9	Surgical Requirements.....	54
1.9.1	Surgical Problems Classification.....	54
1.9.1.1	Minor	54
1.9.1.2	Moderate.....	55
1.9.1.3	Major.....	55
1.9.2	Environment and Surgery.....	55
1.9.2.1	Microgravity Constraints.....	55
1.9.2.2	Countermeasures.....	56
1.9.2.3	Anaesthesia	56
1.9.2.4	Intensive Care Medicine.....	57
1.10	Computerised Health Maintenance System.....	57
1.11	Telemedicine.....	58
1.11.1	Introduction.....	58
1.11.2	Telepresence in Medicine	59
	References	60
CHAPTER 2: Hardware for DOCC.....		65
SECTION II: CORE MODULE DESIGN		
CHAPTER 3: System Overview.....		87
3.1	Definition of the DOCC.....	87
3.2	Core DOCC Requirements	88
3.3	The "Big Picture".....	89
CHAPTER 4: Space Segment.....		93
4.1	Medical Aspects for Space Applications.....	93

4.1.1	Countermeasures Hardware.....	97
4.1.2	Pharmaceutical Kit.....	99
4.1.3	Dental Kit.....	100
4.1.4	Monitoring System	100
4.1.4.1	Medical Monitoring.....	101
4.1.4.2	Radiation Monitoring.....	103
4.1.4.3	Personal Position-Monitoring System (PPMS).....	105
4.1.4.4	Extra Vehicular Activity (EVA) Monitoring.....	106
4.1.5	Computerised Health Maintenance System (CHMS).....	106
4.1.5.1	Computerised Medical Record System	107
4.1.5.2	Advanced Diagnostic and Monitoring Capability	107
4.1.5.3	Access to Electronic Medical Literature for Education and Reference	108
4.1.5.4	Medical Inventory System.....	108
4.1.5.5	Notes About Construction of the CHMS.....	108
4.1.6	Telemedicine and Virtual Reality.....	109
4.1.6.1	The DOCC Telemedicine and Virtual Reality System.....	109
4.1.6.2	The Challenges of Realistic Virtual Reality	110
4.1.6.3	Artificial Intelligence in Medicine.....	110
4.1.7	Medical Architecture Drivers	111
4.2	Data Handling and Communications.....	112
4.2.1	Bandwidth Requirements.....	113
4.2.1.1	Text.....	114
4.2.1.2	Images.....	114
4.2.1.3	Audio	115
4.2.1.4	Video.....	115
4.2.1.5	Dynamic Bandwidth Allocation	116
4.2.2	Data Compression Formats.....	116
4.2.2.1	Common Features of the Compression Codes.....	117
4.2.2.2	Compression Codes	118
4.2.2.3	Relevant Medical Aspects	120
4.2.3	Data Security and Encryption.....	120
4.2.3.1	Currently Used Data Protection Methods.....	121
4.2.3.2	Key Encryption Systems.....	121
4.2.3.3	How it works.....	122
4.2.3.4	Disadvantages of RSA and New Alternatives.....	122
4.2.3.5	Authentication.....	123
4.2.3.6	Conclusions.....	123
4.2.4	Protocols	123
4.2.4.1	Earth-DOCC Transmissions: CCSDS Telemetry and Telecommand.....	124
4.2.4.2	ATM	125
4.2.4.3	Internet.....	126
4.2.4.4	Application Level	126
4.2.4.5	Serial Bus	127
4.2.5	Image Processing.....	130
4.2.5.1	Image Acquisition.....	130
4.2.5.2	Image Display	131

4.2.5.3	Image Analysis	131
4.2.6	Hardware Configuration and Data Storage.....	135
4.2.6.1	General Functions and Architecture	136
4.2.6.2	Communications Media.....	137
4.2.6.3	Computer-to-Network Interfaces.....	137
4.2.6.4	Peripherals	138
4.2.6.5	Processing Capabilities.....	138
4.2.6.6	Data Handling Subsystem.....	139
4.2.6.7	Storage Devices	140
4.2.6.8	Notepad Data Interface.....	143
4.2.6.9	Virtual Reality Facility	144
4.2.7	Ground Segment Requirements.....	144
4.3	Architectural Design.....	144
4.3.1	The Functional Requirements.....	145
4.3.2	Layout and Use of Volume.....	145
4.3.3	Virtual Reality Facility	148
4.3.4	Some Details.....	150
References		151
CHAPTER 5: Ground Segment		155
5.1	Ground Segment Medical Requirements.....	155
5.1.1	Computerised Health Maintenance System.....	155
5.1.2	Surgery.....	156
5.1.2.1	Human Interface	156
5.1.2.2	Hardware.....	156
5.2	Ground Operations Support.....	158
5.2.1	DOCC GCC Functions	159
References		162
CHAPTER 6: DOCC Operations		163
6.1	Pre-Flight Operations.....	163
6.1.1	User Selection.....	164
6.1.1.1	Selection Criteria	164
6.1.1.2	Selection Resources	165
6.1.1.3	Selection Process	165
6.1.2	User Training.....	165
6.1.2.1	Medical Training	165
6.1.2.2	Space Medicine Residency Training Program	167
6.1.2.3	Facility Usage Training	169
6.1.2.4	Training Resources	170
6.1.3	DOCC Facility Start-Up.....	171
6.1.3.1	Initial Supply	171
6.1.3.2	Test Verification.....	171

6.2	In-Flight Operations.....	172
6.2.1	Procedures And Protocols.....	172
6.2.1.1	Procedures.....	172
6.2.1.2	Protocols	173
6.2.1.3	The Current Situation	173
6.2.1.4	Is There a Rationale for Change?	175
6.2.1.5	The Human-Procedure Interface.....	176
6.2.1.6	A Look Into the Future: Advances in Information Technology ...	176
6.2.2	Maintenance and Logistics	179
6.2.2.1	Objective.....	179
6.2.2.2	Basic Concept.....	180
6.2.2.3	Maintenance.....	180
6.2.2.4	Logistics.....	181
6.2.2.5	Required Functions.....	182
6.2.2.6	Maintenance and Logistics Items List (MMIL)	183
6.3	Post-Flight Operations.....	186
6.3.1	User Deconditioning.....	187
6.3.2	Facility Evaluation and Shutdown.....	187
	References	188

SECTION III: CASE APPLICATIONS

Scenarios and Environments	191
Review of Proposed Future Missions.....	191
Scenario Selection Criteria.....	192
Selection of Environments	195
Transportation Issues.....	195

CHAPTER 7: Orbital Application.....197

7.1	Commercial Space Station.....	197
7.1.1	Introductory Scenario	197
7.1.2	Assumed Existing Infrastructure	198
7.1.3	Scenario Dependent Requirements.....	198
7.1.4	Environmental Constraints	199
7.1.4.1	Neutral Atmosphere.....	199
7.1.4.2	Thermal.....	199
7.1.4.3	Ionising Radiation.....	199
7.1.4.4	Meteoroids and Orbital Debris	200
7.1.4.5	Microgravity and Eclipse Duration	200
7.2	Medical Aspects on the Orbital Application Scenario	200
7.2.1	Crew Selection.....	200
7.2.2	Physiological Countermeasures.....	201
7.2.3	Medical Monitoring for an Orbital Station.....	201
7.2.4	Pharmaceutical Kit.....	202

7.2.5	Dental Kit.....	202
7.2.6	Rescue Vehicle	202
7.2.6.1	Medical Problems Requiring Rescue Vehicle	202
7.2.6.2	Medical Requirements For Rescue Vehicle	203
7.2.6.3	Design Goals of Rescue Vehicle	204
7.2.6.4	Conclusions.....	204
7.2.7	Impacts On Architecture.....	204
7.2.8	Computerised Health Maintenance System.....	205
7.3	Space Transportation to Low Earth Orbit.....	205
7.3.1	Introduction.....	205
7.3.2	Existing and Future Vehicles.....	205
7.3.3	Technical Requirements	206
7.3.3.1	Spacecraft Acceleration Load Factors and Vibrations	206
7.3.4	Cargo Transportation System	207
7.3.5	Selection of the DOCC Space Transportation System (DSTS).....	207
7.3.6	Crew Rescue Vehicle (CRV).....	209
7.4	System Architectural Concept.....	210
7.4.1	Architectural Concept.....	210
7.4.1.1	Surgery and Intensive Care.....	213
7.4.1.2	Minor Diagnosis and Treatment.....	214
7.4.1.3	Countermeasures.....	214
7.4.2	Virtual Reality Facility	215
7.5	Adaptation to Core Design	216
7.5.1	Modifications To Core Operations	216
7.5.2.1	Users Selection And Training.....	216
7.5.2.2	DOCC Facility Start-Up.....	216
7.5.2.3	Procedures And Protocols.....	216
7.5.2.4	Maintenance And Logistics	217
7.5.2.5	Users Deconditioning	217
References		217
CHAPTER 8: Mars Application		219
8.1	Mars Scenario	219
8.1.1	Introductory Scenario	219
8.1.2	Assumed Existing Infrastructure	220
8.1.3	Scenario Dependent Requirements.....	220
8.1.4	Environmental Constraints	220
8.2	Medical requirements for the Mars Mission.....	221
8.2.1	Crew Selection.....	221
8.2.2	Physiological Countermeasure Considerations on the Mars Mission Scenario	222
8.2.2.1	Biological Damages of Radiation Exposure.....	223
8.2.2.2	Biological Damages of Radiation Exposure Countermeasures....	224

8.2.3	Pharmaceutical Kit.....	225
8.2.4	Dental Kit.....	226
8.2.5	Medical Monitoring for a Mars Mission	226
8.2.6	Impacts on Architecture.....	226
8.2.7	Computerised Health Maintenance System.....	227
8.2.8	Virtual Reality for Medical Training on Mars	227
8.3	Transportation to Mars	228
8.3.1	Mission Description.....	228
8.3.2	Propulsion Systems.....	229
8.3.3	Vehicle Configuration	229
8.3.4	Requirements on Volume and Mass.....	230
8.4	Architectural Concept.....	232
8.4.1	General Design Considerations	232
8.4.1.1	Major Design Inputs	233
8.4.1.2	Function Priority VS. Average Usage Time.....	235
8.4.1.3	General Hardware Groups	235
8.4.2	Specific Design Considerations and Conclusions	237
8.4.2.1	Puzzling the Hardware into Larger Units	238
8.4.2.2	Spatial Concept.....	240
8.4.2.3	Further Ideas	242
8.4.2.4	Usage Concept.....	242
8.4.2.5	Some Three-Dimensional Sketches.....	244
8.4.3	Virtual Reality Facility	247
8.5	Adaptation to Core Design	249
8.5.1	Communications Constraints on a Mars Mission.....	249
8.5.2	Mars Modifications to Core Operations	251
8.5.2.1	Users Selection and Training.....	251
8.5.2.2	DOCC Facility Start-Up	251
8.5.2.3	Procedures and Protocols.....	252
8.5.2.4	Maintenance and Logistics	252
8.5.2.5	Users Deconditioning	252
	References	253

SECTION IV: BUSINESS AND LEGAL ISSUES

CHAPTER 9: DOCC Business Aspects.....	257
9.1 The DOCC “Product”	257
9.1.1 The Product Definition	257
9.1.2 “First Generation” Facilities	258
9.1.3 Relating Product Advantages to Customers	259
9.1.4 SWOT Analysis.....	259
9.2 Market Issues	260
9.2.1 Potential Customers	261

9.2.1.1 Governments.....	262
9.2.1.2 Private Sector.....	263
9.2.1.3 International Non-Profit Organisations	264
9.2.2 Customer Buying Decision.....	264
9.2.3 Price.....	264
9.2.4 Promotion	265
9.2.5 Distribution Channels.....	265
9.3 Commercialisation.....	266
9.3.1 Development.....	266
9.3.2 Barriers to Commercialisation.....	267
9.3.3 Transfer of Technologies.....	268
9.4 Costing	269
9.4.1 Cost Breakdown.....	269
9.4.2 Cost Estimation Methods.....	270
9.4.2.1 Non-Recurring and Recurring Costs	270
9.4.2.2 Transportation Costs.....	271
9.4.2.3 Operational Costs.....	272
9.4.2.4 Insurance Costs.....	272
9.4.3 Costs	272
9.4.3.1 DOCC Cost Estimates	272
9.4.3.2 Transportation Estimates	272
9.4.3.3 Operation Yearly Cost Estimates.....	273
9.4.3.4 Insurance Cost Estimates.....	273
9.4.4 Cost Drivers.....	273
9.4.4.1 DOCC Items	273
9.4.4.2 Transportation.....	274
9.4.4.3 Ground Control Centre (GCC) and Operations.....	274
9.4.4.4 Insurance.....	274
9.4.5 Recommendations for Cost Reductions.....	274
9.4.5.1 DOCC Items	274
9.4.5.2 Ground Control Centre (GCC) and Operations.....	275
9.4.5.3 Insurance.....	275
9.5 Business Concepts	275
9.5.1 The Pre-Development Phase.....	275
9.5.2 A Design Implementation Model	276
References	278
CHAPTER 10:POLITICAL AND LEGAL ISSUES	279
10.1 Political Issues Introduction	279
10.2 Imminent Medical Advances.....	280
10.3 Governmental Decision Making	281

10.4	International Co-operation.....	281
10.4.1	General Advantages of Co-operation	281
10.4.2	General Disadvantages of Co-operation.....	281
10.4.3	Co-operation and the DOCC	282
10.5	Political Decision Making	283
10.6	Why Fund the DOCC?.....	283
10.6.1	International and National Prestige	283
10.6.2	Potential Terrestrial Applications.....	284
10.6.3	Technology Development	284
10.6.4	Medical Infrastructure for Future Manned Missions.....	285
10.7	Commercialisation of DOCC	286
10.7.1	Economic Interest of Private Sector	286
10.7.2	The Development Stage.....	287
10.7.3	The Operational Stage	288
10.8	Administration.....	289
10.8.1	Allocation of Use.....	290
10.8.2	Discretion of Use: Public/Private Entities	290
10.9	Legal Issues Introduction.....	290
10.10	The Outer Space Treaty	291
10.11	The Rescue Agreement.....	292
10.12	A Sample Framework.....	292
10.13	Intellectual Property.....	293
10.13.1	“First-to-File”	294
10.13.2	“First-to-Invent”	294
10.13.3	Infringement of Patent Rights.....	294
10.13.4	Recommendations	295
10.14	Privacy	295
10.14.1	The Distant Health Care and the Right Of Privacy	295
10.14.2	Space Law and the Right of Privacy.....	296
10.14.3	Restrictions on the Right of Privacy of Professional Astronauts	297
10.14.4	How to Secure The Confidentiality of Personal Data	298
10.15	Liability Issues.....	299
10.15.1	Telemedicine and Liability	299
10.15.2	Liability of the Parties Involved in DOCC	300
10.15.2.1	Liability of the Astronauts Aboard the Spacecraft	300
10.15.2.2	Liability of the Consulting Physician	301
10.15.2.3	Manufacturer’s Liability	302

10.15.2.4 Operator's Liability	302
10.15.2.5 Concurrent Liability.....	303
10.15.3 Liability Issues Conclusion.....	303
10.16 World Health Organisation.....	303
References	305
 SECTION V: CONCLUSIONS	
CHAPTER 11:DOCC PROJECT RISK ASSESSMENT.....	309
11.1 Design and Architecture of Modularity and Adaptability	309
11.1.1 Risk Evaluation.....	310
11.1.2 Actions to be Taken.....	310
11.2 Core Design	310
11.2.1 Risk Evaluation.....	311
11.2.2 Actions to be Taken.....	311
11.3 DOCC Hardware and Service for Terrestrial Use	311
11.3.1 Hardware.....	311
11.3.2 Services.....	311
11.3.3 Risk Evaluation.....	312
11.3.4 Actions to be Taken.....	312
11.4 Commercialisation.....	312
11.4.1 Risk Evaluation.....	313
11.4.2 Actions to be Taken.....	313
11.5 Applications of DOCC in Developing Countries.....	313
11.5.1 Risk Evaluation.....	313
11.5.2 Actions to be Taken.....	313
11.6 Marketing the DOCC Through an Established Medical Company	314
11.6.1 Risk Evaluation.....	314
11.6.2 Actions to be Taken.....	314
11.7 Summary.....	314
CHAPTER 12:RECOMMENDATIONS	315
12.1 Crew Selection.....	315
12.2 Physiological Countermeasures.....	315
12.3 Psychological Countermeasures.....	316
12.4 Surgery	316

12.5 Pharmaceuticals	317
12.6 Telemedicine.....	317
12.7 Space Medicine Residency Training Program	317
12.8 Computerised Health Maintenance System.....	317
12.9 Increased Crew Autonomy	318
12.10 In-Flight Training	318
12.11 Automated Inventory Tracking.....	318
12.12 Data Handling and Communications.....	319
12.13 Policy and Law	319
12.14 System Architecture.....	320
12.15 Risk Assessment	320

APPENDICES

A. Work Breakdown Structure.....	323
B. Project Structure for Different Environments	325
C. Event Driven Analysis of Medical Problems Expected to Occur During Space Activities.....	327
D. Funcional DOCC Hardware List.....	339
E. Alphabetical DOCC Hardware List	341
F. References for Section 1.3 and 1.4.....	347
G. Space Transportation to Low Earth Orbit	353
G.1 Existing and Future Vehicles.....	353
G.2 Crew Rescue Vehicle	356
G.2.1 Escape Vehicle EV-0.....	356
G.2.2 Escape Vehicle EV-1	357
G.2.3 Escape Vehicle EV-2.....	358
G.2.2 Soyuz as an Escape Vehicle	359
References	359
H. DOCC Hardware List for Mars.....	361

List of Figures

Figure 3.1	DOCC System Block Diagram - “Big Picture of DOCC”	90
Figure 4.1	Example of Telemetry Data Flow (CCSDS 102.0-B-4)	125
Figure 4.2	OSI Layers of Definition	127
Figure 4.3	The P1394 Architecture	128
Figure 4.4	Section View of the Cable	129
Figure 4.5	Digital Image File	131
Figure 4.6	Image Processing System Highlighting the Role of the Data Base	134
Figure 4.7	Configuration of DOCC’s Computer and Network System	136
Figure 4.8	Data Flow within DOCC’s Information System	140
Figure 4.9	The Structure of the DOCC On Board Storage Components	141
Figure 4.10	The Arrangement of the Core Rack	146
Figure 4.11	An Exploded View of the Core Rack Showing the Arrangement of Equipment	147
Figure 4.12	The Bed	147
Figure 4.13	The Use of Core Module Space	148
Figure 4.14	A Concept of the Bed	150
Figure 4.15	The Bed from Above	151
Figure 5.1	Operator with the Handles and a View of the Slave Unit Working in the Surgical Field (SRI International)	157
Figure 5.2	Interchangeable Tools (SRI International)	157
Figure 5.3	Console Unit and Remote Slave Unit (SRI International)	158
Figure 5.4	Surgical Robot Operating on a Patient “Dummy”	158
Figure 5.5	GCC Interactions with Space and Ground Resources	159
Figure 6.1	Xybernaut Wearable PC	177
Figure 6.2	Use of Augmented Reality for Location of DOCC Hardware and Resources	178
Figure III.1	Review of Future Mission Scenarios	192
Figure 7.1	Low Earth Orbit Resupply Cycle	207
Figure 7.2	ESA Crew Rescue Vehicle	210
Figure 7.3	Proposed Orbital DOCC Configuration	211

Figure 7.4	Exploded View of the Orbital DOCC Facility	212
Figure 7.5	Use of the DOCC Volume for a LEO Space Station Application	212
Figure 7.6	Sterile Surgical Racks (shown hatched)	213
Figure 7.7	Intensive Care Racks	214
Figure 7.8	Countermeasures Racks	215
Figure 8.1	Schematic Picture Showing Possible Sites and Mechanisms of Action of Radioprotectants	224
Figure 8.2	Mars Transfer Vehicle Based on NEP	230
Figure 8.3	Volume Requirements per Person for Long Duration Flights	230
Figure 8.4	Scheme of the Living and the Working Module of the Habitat of the Transfer Vehicle	231
Figure 8.5	Mission vs. Medical Requirements and Risks	232
Figure 8.6	Draft of the Medical Bed	238
Figure 8.7	A Cross-Sectional View of a DOCC	240
Figure 8.8	DOCC from Above	241
Figure 8.9	Different Usage Configurations	243
Figure 8.10	Medical Facility Separated by the Retractable Wall	244
Figure 8.11	Usage Scenario A According to Figure 8.9	245
Figure 8.12	Usage Scenario B According to Figure 8.9	245
Figure 8.13	View of Usage Scenario B	246
Figure 8.14	View of Usage Scenario B	246
Figure 8.15	View of Usage Scenario B	247
Figure 8.16	Another Possible Form of Exercise for Bored Crews on Long Missions	248
Figure 9.1	Estimate by Terrestrial Analogy	270
Figure 9.2	Estimate by Space Analogy	271
Figure 9.3	Parametric Estimate	271
Figure 9.4	Design Implementation Model	277

List of Tables

Table I.1	Case Application General Parameters	6
Table 1.1	Event Driven Analysis of Medical Problems	16
Table 1.2	Physiological and Physical Stressors in the Spaceflight Environment	26
Table 1.3	Characteristics of Astenic Syndrome	26
Table 1.4	Stressors in the Spaceflight and Space Analogue Environments	27
Table 1.5	Effects of Spaceflight and Space-Analogue Environments	29
Table 1.6	Suggested Countermeasures Coupled with the Origin of Disturbance of the Immune System	52
Table 2.1	Functional Hardware List	66
Table 3.1	Function Allocation of Each DOCC Facility	91
Table 4.1	Core Facility Definition	94
Table 4.2	Contents of Dental Kit	100
Table 4.3	Required Medical Hardware for the Medical Monitoring System	102
Table 4.4	Monitoring Routine	103
Table 4.5	Relation between the kind of Radiation and the RBE	104
Table 4.6	Overview about Different Radiation Environments	104
Table 4.7	Comparison of the Active and Passive Position Monitoring	106
Table 4.8	Relationships of DOCC Hardware and Subsystems	112
Table 4.9	Typical Bandwidth Sizes	113
Table 4.10	Media Types, Sample Formats, Data Volume and Transfer Rate	114
Table 4.11	Different Data Types	140
Table 4.12	Performance and Capacity of Storage Devices	142
Table 6.1	Training Program for a Space Medicine Specialist (SMS)	169
Table 6.2	Training Curriculum for a Space Medicine Specialist (SMS)	169
Table 6.3	Methods of Keeping High Availability	179
Table 6.4	Maintenance and Logistics Functional Requirements Application	183
Table 6.5	Maintenance and Logistics Items List (MLIL)	183
Table III.1	Selected Mission Scenarios	193

Table 7.1	Required Medical Hardware for the “Medical Monitoring System” on the Orbital Facility	201
Table 7.2	Monitoring: Routine for the Orbital Facility	201
Table 7.3	Existing and Future Launchers Capable of Space Station Support	206
Table 7.4	Maximum Axial and Lateral Acceleration During Lift-Off and Landing of the Space Transportation System	206
Table 7.5	Space Transportation System Axial and Lateral fundamental Frequencies	207
Table 8.1	Special Monitoring Requirements for the Mars Mission	226
Table 9.1	SWOT Analysis	260
Table 9.2	DOCC Potential Customers	261
Table 9.3	Phases of Development of the DOCC Project	267
Table 9.4	DOCC Cost Estimates	272
Table 9.5	Transportation Estimates	272
Table 9.6	Operation Cost Estimates	273
Table 9.7	Insurance Cost Estimates	273

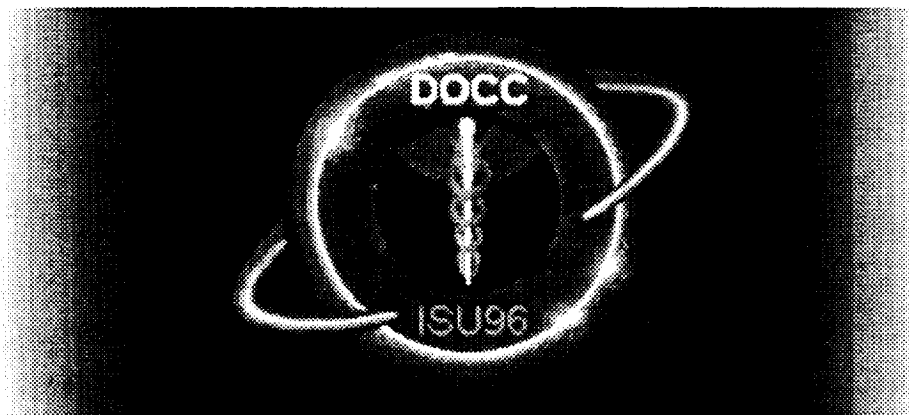
Acronyms

ADPCM	Advanced Pulse Code Modulation
AI	Artificial Intelligence
ANSI	American National Standards Institute
ASCII	American Standard Code for Information Interchange
ASM	The Austrian Society for Aerospace Medicine
ATM	Asynchronous Transfer Mode
B/W	Black/White
BIT	Built In Test
BMD	Bone Mineral Density
BP	Blood Pressure
BST	Basic Spacecraft Training
C	Centigrade
CBC	Cell Blood Count
CCITT	Consultative Committee International Telegraph and Telephone
CCSDS	Consultative Committee for Space Data System
CD	Compact Disk
CEIT	Crew Equipment Integration Test
CHMS	Computerised Health Maintenance System
CM	Countermeasures
CMO	Crew Medical Officers
COMS	Communications
CPE	Contamination Protection System
CPR	Cardio Pulmonary Resuscitation
CPSS	Crew Psychological Support System
CSA-CP	Compound Specific Analyser - Combustion Products
CSA-H	Compound Specific Analyser - Hydrazine
CT	Computed Tomography
CU	Console Unit
CV	Cardiovascular
DA	Digital Audio
DCE	Data Circuit-terminating Equipment
DCT	Discrete Cosine Transform
DHS	Data Handling System
DIS	Distributed Interactive Simulation
DMS	Diagnostic Medical System
DNA	Desoxyribonucleic Acid

DOCC	Distant Operational Care Centre
DRAMS	Dynamic Random Access Memories
DSTS	DOCC Space Transportation System
DTE	Data Terminating Equipment
ECG	Electrocardiogram/Electrocardiograph
ECLSS	Environmental Control and Life Support System
EEG	Electroencephalograph
ENT	Ear, Nose and Throat
EPA	Environmental Protection Agency
EPS	Electrical Power System
ESA	European Space Agency
ETEBAC	Exchange Telematique Entre les Banque et leurs Clients
ETSI	European Tele-communications Standards Institute
EVA	Extra-Vehicular Activity
FDF	Flight Data File
FDIR	Failure Detection, Isolation and Reconfiguration
fMRI	functional MRI
GCC	Ground Control Centre
GCR	Galactic Cosmic Rays
GeV	Giga Electron Volts
GIF	Graphics Interchange Format
GIS	Geographical Information System
GNC	Guidance Navigation and Control
GPS	Global Positioning System
GUI	Graphical User Interface
GYN	Gynaecology
H/W	Hardware
HCT	Hematocrit
HDTV	High Definition Television
HTML	Hypertext Mark-up Language
HZE	High Z and Energy
I/O	Input/Output
IBCSM	International Board Committee for Space Medicine
ICU	Intensive Care Unit
IEEE	Institute of Electrical and Electronics Engineers
IGA	Inter Governmental Agreement
IP	Intellectual Property
ISO	International Standardisation Organisation
ISS	International Space Station
ISU	International Space University
ITU	International Telecommunications Union
IUS	Inertial Upper Stage
IV	Intravenous

IVT	Integration Verification Test
JBIG	Joint Bilevel Image Group
JPEG	Joint Photographic Experts Group
LBNP	Lower Body Negative Pressure
LCD	Liquid Crystal Display
LCD	Liquid Crystal Display
LEO	Low Earth Orbit
MCHC	Mean Corpuscular Hemoglobin Concentration
MCS	Medical Computer System
MCV	Mean Corpuscular Volume
MEG	Magnetoencephalography
MEO	Medium Earth Orbit
MGA	Metabolic Gas Analyser
MHFDF	Mobile Hypermedia Flight Data File
MIM	Media Interface Modul
MIS	Medical Information System
MLIL	Maintenance and Logistics Items List
MMCH/Y	Mean Maintenance Crew Hour per Year
MPEG	Moving Pictures Experts Group
MR	Magnetic Resonance
MRI	Magnetic Resonance Imaging
MTBF	Mean Time Between Failure
MTTR	Mean Time To Repair
NASA	National Aeronautics and Space Administration
NDI	Notepad Data Interface
NTSC	National Television Standards Committee
ORU	Orbital Replacement Unit
OSM	Orbital Servicing Module
OST	Outer Space Treaty
PAL	Phase Alternate Lines
PCM	Pulse Code Modulation
PCT	Private Communication Technology
PDA	Personal Digital Assistant
Pet	Platelets
PGP	Pretty Good Privacy
PN	Pseudo-random Noise
PPMS	Personal Position Monitoring System
PR	ECG Interval Points
PRC	Practical Year
PSM	Patient Status Monitor Unit
PTH	Parathyroid Hormone
QR	ECG Interval Points
R&D	Research And Development

RAID	Redundant Arrays of Independent Disks
RAM	Random Access Memory
RBC	Red Blood Cells
RBE	Radiobiological Effectiveness
RC	Re-entry Capsule
RF	Radio Frequency
ROI	Region Of Interest
ROM	Read Only Memory
RSA	Cryptosystem, named after the inventors: Rivest, Shamir, Adleman
RSA	Robotic Surgical Assistant
RSU	Remote Slave Unit
S-HTTP	Secure Hyper Text Transmission Protocol
S/MIME	Secure/Multipurpose Internet Mail Extensions
SC	Spacecraft
SCSI	Small Computer System Interface
SEPP	Science and Environmental Policy Project
SFP	Single Failure Point
SMS	Space Medicine Specialist
SSTR	Space Surgeon Residency Program
STS	Space Transportation System
STT	Secure Transaction Technology
SW	Software
SWIFT	Society for Worldwide Interbank Financial Telecommunications
TCP/IP	Transmission Control Protocol/Internet Protocol
TCS	Thermal Control System
TEPC	Tissue Equivalent Proportional Counter
TFT	Thin Film Transistor
TIFF	Tagged Interchange File Format
TOC	Total Organic Carbon Analyser
TPS	Thermal Protection System
TSH	Thyroid Stimulating Hormone
U.S.	United States
UCS	Urine Collection System
UPS	Uninterruptable Power Supply
UTMB	The University of Texas - Medical Branch
VOA	Volatile Organic Analyser
VR	Virtual Reality
VRF	Virtual Reality Facility
VRML	Virtual Reality Modelling Language
WBC	White Blood Cells
WHO	World Health Organisation
WSU	Wright State University



DOCC

DISTANT OPERATIONAL
CARE CENTRE

EXECUTIVE SUMMARY





EXECUTIVE SUMMARY

YOUR LOVED ONES WERE DARING AND BRAVE, AND THEY HAD THAT SPECIAL GRACE, THAT SPECIAL SPIRIT THAT SAYS, 'GIVE ME A CHALLENGE AND I'LL MEET IT WITH JOY.

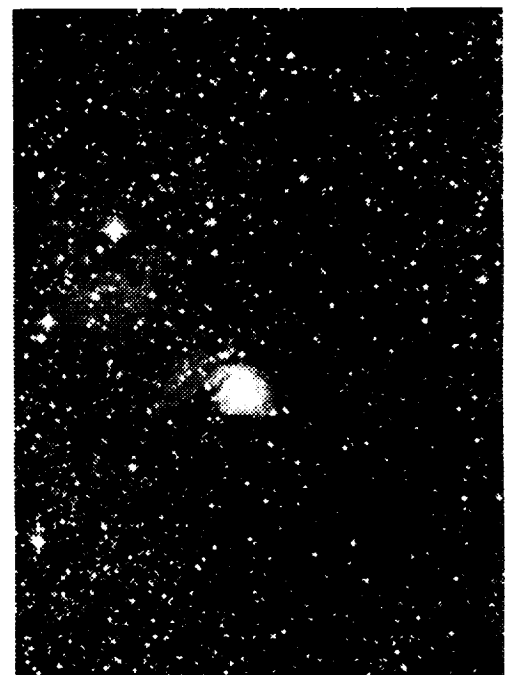
-PRESIDENT REAGAN'S SPEECH ON THE CHALLENGER DISASTER (1986)

INTRODUCTION

Space is a dangerous place for humans. Behind the carefree smiles of astronauts and cosmonauts, there lies a serious awareness that they risk their very lives in the name of discovery. In the light of the dangers of micro-gravity, radiation, space sickness, and potential error and failure, the weakest link in space exploration are the humans. They carry the hopes and aspirations of entire nations. And they can be shot down by something as minuscule as a micrometeorite.

Space is a future frontier for a range of remote human habitats. From a few days to half a year, from low Earth orbit to Mars, the space frontier beckons professionals and non-professionals, explorers and entrepreneurs, scientists and politicians with

rich new opportunities. Higher, bigger, longer, future space ventures only make the dangers of space even more immediate. It is essential that tomorrow's space doctor must be armed with new medical technologies and innovations against the unknown future medical challenges of space.



Taking a "medicine-first" approach to space medicine, working from a general medical perspective, studying and establishing a foundation of common medical functions and hardware, has never been explored before thoroughly until this design project. This design project will go further by tying in the medical, technological, operational, managerial, legal, and business requirements and implications, as well as their interdisciplinary issues, in the context of increased frequency, duration, and complexity of future human spaceflight.

MISSION STATEMENT

The goal of this project is to outline the design of the Distant Operational Care Centre (DOCC), a modular medical facility to maintain human health and performance in space, that is adaptable to a range of remote human habitats.

The purpose of this project is to outline a design, not to go into a complete technical specification of a medical facility for space. This project involves a process to produce a concise set of requirements, addressing the fundamental problems and issues regarding all



aspects of a space medical facility for the future. The ideas presented here are at a high level, based on existing, researched, and hypothetical technologies. Given the long development times for space exploration, the outlined concepts from this project embodies a collection of identified problems, and corresponding proposed solutions and ideas, ready to contribute to future space exploration efforts. In order to provide a solid extrapolation and speculation in the context of the future of space medicine, the extent of this project's vision is roughly within the next two decades.





The Distant Operational Care Centre (DOCC) is a modular medical facility for space. That is, its function is to maintain human health and performance in space environments, through prevention, diagnosis, and treatment. Furthermore, the DOCC must be adaptable to meet the environmental requirements of different remote human habitats, and support a high quality of human performance. To meet a diverse range of remote human habitats, the DOCC concentrates on a core medical capability that can then be adapted. Adaptation would make use of the DOCC's functional modularity, providing the ability to replace, add, and modify core functions of the DOCC by updating hardware, operations, and procedures. Some of the challenges to be addressed by this project include what constitutes the core medical capability in terms of hardware, operations, and procedures, and how DOCC can be adapted to different remote habitats.

CORE MODULE

The elements of the DOCC core module consist of medical, operational, communication and architectural aspects. Based on these aspects an actual design of the core module is made.



MEDICAL ASPECTS

CASE HISTORY OF THE FUTURE:

A 27 year old male astronaut on an extended Mars mission who is suspected of having a fracture of his left lower leg comes to the DOCC for medical treatment.

While performing an EVA (Extra Vehicular Activity) to repair a faulty solar array on the Mars orbital station, the control manipulator arm he was using malfunctioned and crushed his leg against the outer wall of the space vehicle. His space suit was not punctured.

The patient has been in a microgravity environment for the past nine months. The patient states that he often "for-

gets" to perform his counter-measure exercises and so he is suspected of suffering from microgravity induced osteoporosis.

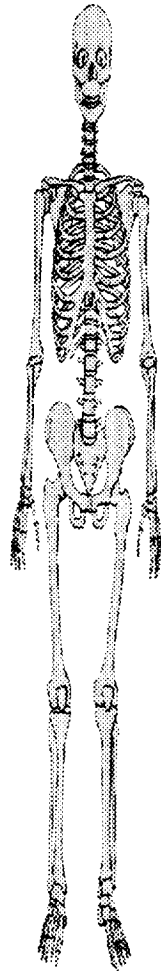
On examination by the onboard medical personnel, the patient is breathing rapidly and has a high heart rate and low blood pressure. The patient is very tender on the left lower leg and has a large swelling and blue discoloration in this area. Examination indicates no loss of blood flow or nerve function in the affected leg.

The patient is given medication for pain and given intravenous fluids. An X-ray is then performed and confirms a crushed left tibia and fibula.

The patient's fracture is stabilised and then he is returned to the ground station on Mars where he receives surgery to fixate the bone. He remains on the surface of Mars where he is treated with medication and counter-measures. After four months, the patient has returned to duty on the orbital station, but is restricted from performing EVA's.

During any expedition, including space expeditions, human health must always be the first priority. From the above scenario, it is clear that

as with the Earth environment, a variety of medical problems can occur in a remote space environment. The DOCC must be prepared to treat any medical problem that can occur in a space environment.



The design process of the DOCC starts with the **medical risk assessment**. This covers all medical events which are likely to be encountered during space flight, the medical procedures, the countermeasures, the treatment, and the hardware needed. Medical events that could occur are partly similar to those on Earth, like infections and injuries, but they have different likelihoods. On the other hand there are space specific cases like Space Adaptation Syndrome and deconditioning of the cardiovascular, skeletal, muscular, neu-

rosensory, and immune system. Medical procedures and treatment are needed to cure illnesses and to countermeasure deconditioning.

Another medical aspect is **crew selection**. Candidates are evaluated using physical and mental screening to rule out serious medical risk factors. Psychological and psy-





chosocial selection criteria will be developed to select-in individuals with attributes found to be optimal for withstanding the effects of long-duration spaceflight. The selection criteria should periodically be reviewed to evaluate its accuracy.

The **medical crew** consists of medical officers and a space physician. A medical officer is not a medical doctor but has received medical training and is responsible for providing in-flight medical care. The space physician should attend the space surgeon training residency program, which is a space mission oriented medical education.

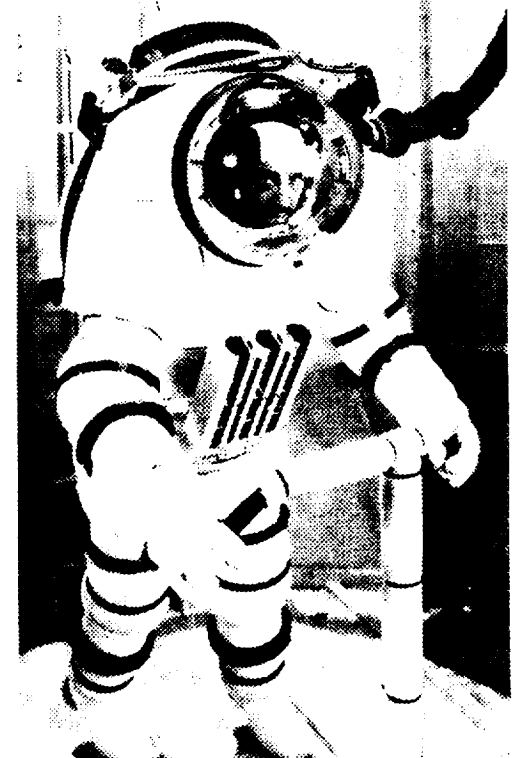
To maintain human health and performance in space, various aspects have been considered. These are discussed below.

Psychological support and physiological countermeasures are basic parts of health maintenance in space. All aspects of crew psychological health and performance throughout all phases of flight are tasked by the **Crew Psychological Support System (CPSS)**, which includes a ground based psychological support team. During long term space flight psychological stressors (due to human-technology interface, and environmental interface), and psycho-social

stressors must be addressed. Deconditioning can be countermeasured by mechanical loading during exercising using treadmills, ergometers, bungy cords, etc. Other countermeasures include pharmaceutical treatment, Lower Body Negative Pressure device, and G-suits.

To prevent and cure medical disorders and to optimize crew performance, **pharmaceuticals** are included in the DOCC. The type of medications are based on the **pharmacodynamics** in the human body which may be altered due to microgravity. The amount of drugs is highly dependent on crew activities, mission duration, and crew size.

Another aspect that should be considered for manned



missions is **dental care**. The dental care comprises of the regular dental check-up and the dental kit needed for this procedure. The dental kit consists of two separate parts. One contains the equipment and the other the consumables. Only the latter part varies with mission duration.

With increasing mission duration a need for **surgical intervention** will arise. Therefore the DOCC is equipped with surgical equipment. Trauma and surgical problems that might occur can be categorised into minor, moderate, and major. Examples of minor problems are lacerations and first degree burns. Appendicitis and fractures of small bones are examples of moderate problems, and second/third degree burns and internal haemorrhage are examples of major disorders. Endoscopic surgery could overcome the problems that are expected to occur during open surgery in microgravity. Other possible solutions are artificial gravity or the use of a glovebox (a sealed containment facility). In addition the DOCC will also support a **monitoring system** and a **Computerized Health Maintenance System (CHMS)** to aid the medical personnel to support crew health. The monitoring system consists of medical mon-

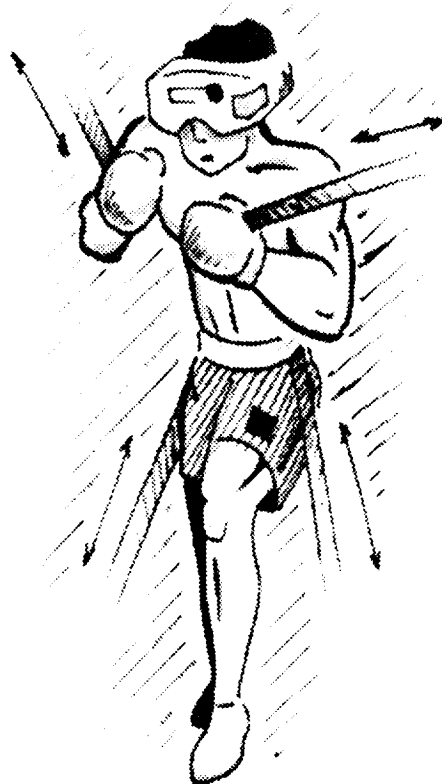
itoring, radiation monitoring, personal position-monitoring, and EVA monitoring. The medical monitoring system describes the medical examination methods including blood, fecal, and urine-analysis, physical and psychological examination. Since radiation in space is an immense danger to humans, radiation monitoring is of great importance to determine the individual doses the crew have received and to determine whether appropriate actions are necessary. The personal positioning-monitoring system is used to qualify the individual radiation dose. EVA monitoring is necessary to monitor the crew member's health in the harsh space environment. The CHMS provides: computerised medical records, interpretation of physiological data, communication with the ground, access to electronic medical literature, a medical inventory system and control of input and output from/to medical devices. These tasks could be accomplished via artificial intelligence in the future. For situations where the communication time between the DOCC and the ground segment is long, the computerised diagnostic system will be used more extensively than telemedicine for emergency situations.





Telemedicine is one of the upcoming technologies which will help the space physicians to practice medicine by delivery of medical information via a computer network. Telemedicine applications on the DOCC will include real time consultation with physicians on the ground.

Virtual reality can be used in the DOCC to practice medical procedures and make countermeasure training more enjoyable by incorporating games, enhancing communication between the ground and space segment and producing a more interactive environment.



GROUND SEGMENT AND OPERATIONS

In addition to the medical functions directly related to the patient there are functions that are related to the DOCC space segment in operation.

The **Ground Control Centre (GCC)** will manage and control the DOCC ground operations. The GCC will monitor the medical facility continuously, provide it with specialized medical data and expertise, and will receive and send multimedia information. Maintenance and resupply are other functions that the GCC will fulfill. In order to do this, a mirror system of the in-flight software and hardware is available on the ground and can be used by specialists through a **communication network**. A general surgeon is continuously available and can be assisted by specialized surgeons on a consultant basis. Of particular interest is the case of telesurgery where surgery can be performed on the ground by using robotical surgical assistance.

The GCC will also take care of **pre-flight operations**. The GCC medical staff is responsible for selection of the users of the DOCC space segment. These future users

will need to graduate from the **Space Surgeon Training Residency (SSTR)** programme, which will be based on the need for a doctor for long duration spaceflight. Each user will receive training in the use of the DOCC equipment. This training will continue in space in unexpected and planned training sessions. Medic's will be trained in repairing and maintaining the facility. The GCC coordinates the design integration, verification testing, initial installation and supply.

For the in-flight phase, procedures need to be developed since tasks in space are complex and hazardous. **Procedures** will be established to aid the diagnosis of medical problems, to instruct on the use of medical and countermeasure equipment. A helpful tool for procedure training can be virtual reality. **Protocols** will be needed when difficult decisions have

to be made. An example is the case of two injured astronauts that need treatment. Who is to be treated first?

One of the most important issues of the GCC is how to maintain the DOCC availability at a maximum. Considerations have been made on how to prevent failures (increase **reliability**) and how to take care of failures (**maintainability**). To achieve acceptable reliability and maintainability the DOCC provides functions such as automatic detection of failures, use of orbital replacement units, resupply, return and spare storage.

The GCC will also be responsible for overseeing the deconditioning of DOCC users once the mission has been completed. Programs will be developed for conditions such as effects of microgravity, radiation, stress, and isolation. In order to periodically evaluate the DOCC facility, it will be taken out of





service at either the end of the mission life, or at the end of a three year service period. At the end of its lifetime the DOCC will be transported to the GCC for disposal and for possible reuse of components.

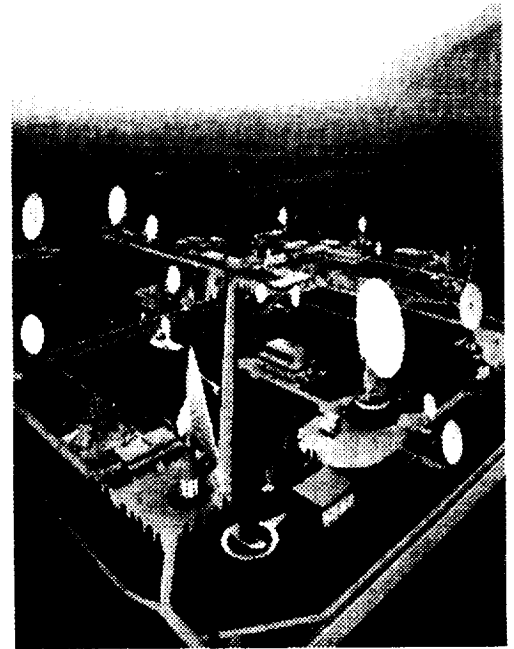
COMMUNICATIONS

All these sophisticated medical functions and operational procedures of DOCC clearly show that the efficient handling of medical information on board the facility calls for careful consideration of many aspects of **processing, storage and transmission** of these data.

The state-of-the-art techniques of these aspects are discussed in relation to the requirements imposed by the telemedicine subsystem of the DOCC. These requirements enable both on-board medical practices as well as the provision of support from the GCC, including audio and video links.

The mission of which DOCC will be a subsystem has to allocate variable bandwidth to the DOCC facility, depending on the different tasks (video, X-ray images, etc.). This issue is solved by a dynamic bandwidth allocation depending on the task and/or priority.

State-of-the-art of various **data compression** for-



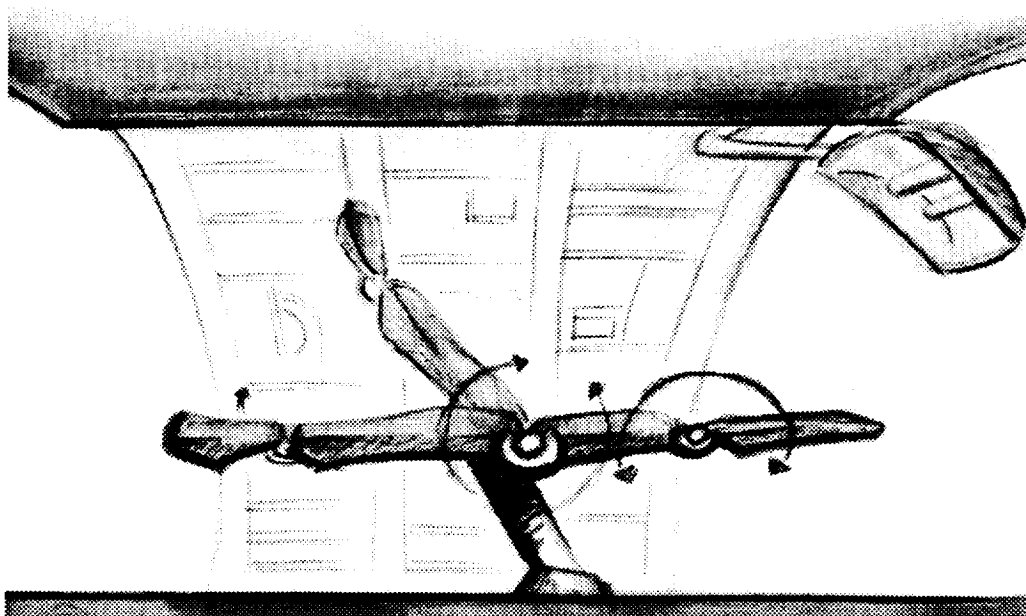
mats are discussed. At the moment it is not possible, even with the highest bit rates, to transmit audio, images or videos efficiently without compressing the information. A further important issue when considering the passing of medical data between the facility and the ground station is the issue of **security**, and in considering this, traditional and emerging data protection and encryption methods are discussed. A powerful aid to diagnosis and treatment of medical problems is image processing. This can range from the simple, effective display of medical imaging data, to more complex, three-dimensional reconstruction techniques and virtual reality facilities. Various image analysis techniques are dis-

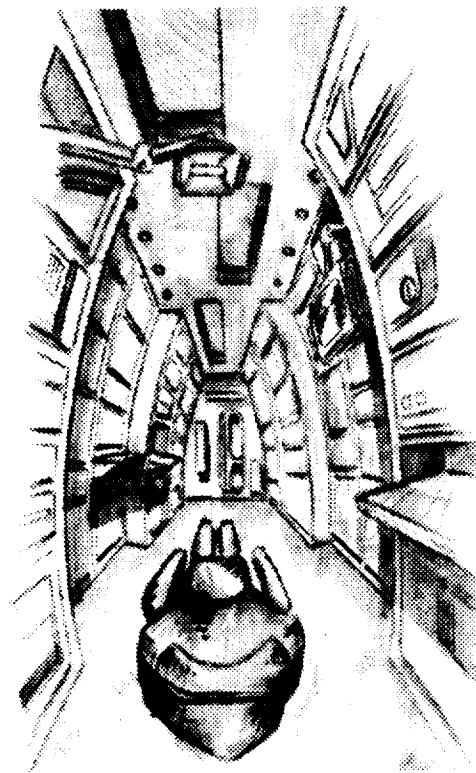
cussed within the context of medical requirements. Data handling and processing such as this requires a competent computer system including adequate processing power and efficient, robust data storage means. Computers and system architecture are discussed including protocols, hardware and software recommendations. Important to know is that the techniques existing today can already be used in DOCC applications. Even the bandwidth required for the different medical applications indicate that this resource will not dramatically limit the performance of the DOCC. Just video applications could suffer bandwidth limitation in long distance locations as Mars. In the future, further improvements are expected which will result in the optimization of

the DOCC performance. A clear example of a similar system existing on other science fields is the GIS (Geographical Information System). The generalization of this concept for medical applications will result in the **MIS (Medical Information System)** concept. The integration of all kinds of medical data in a computer based system formed by databases and data storage devices will help the medical community to take full advantage of the data acquired by the different means at their disposal.

ARCHITECTURE

As human medical needs rarely change much, the functions which have to be performed in the medical facility are independent of missions, such as diagnostic functions (e.g. X-ray imaging), computer supported





diagnosis, surgical operations or just to offer a set of drugs for minor medical problems, the so called core functions. Therefore, the DOCC is designed to have **modularity, adaptability, and expandability** in order to develop it and spin off from the existing Earth applications easily.

The core of the DOCC is a set of functional, hardware and environmental elements chosen to meet the needs of people in a 'generic' situation since humans tend to suffer much the same problems wherever they are. The fact that the design is to be used in space means that there are certain constraints but these constraints are common to all space applica-

tions. The DOCC is designed to be integrated into missions; it should be as flexible as possible.

The medical equipment and functions specified by the medical requirements are integrated into a functional architecture which provides the core medical capability for the DOCC, also called the core module. The goal of the architecture of the core module is to preserve the modularity of the core frame so that it can be easily adapted to a broad range of gravity and microgravity environments in a variety of mission scenarios. To develop this core unit, the list of medical treatments was divided into three families. Serious treatments are those involving major intervention such as surgery; minor treatments are those appropriate to minor problems such as cuts or sore throats; countermeasures are those day-to-day activities needed to maintain health and fitness in space. Each list of treatments defines a set of hardware and functions to be performed to carry out the treatment and the spatial relationship between the hardware and functions and the patients and doctors. The core module design provides an environment which allows the three types of treatment to co-exist in a spatially compatible

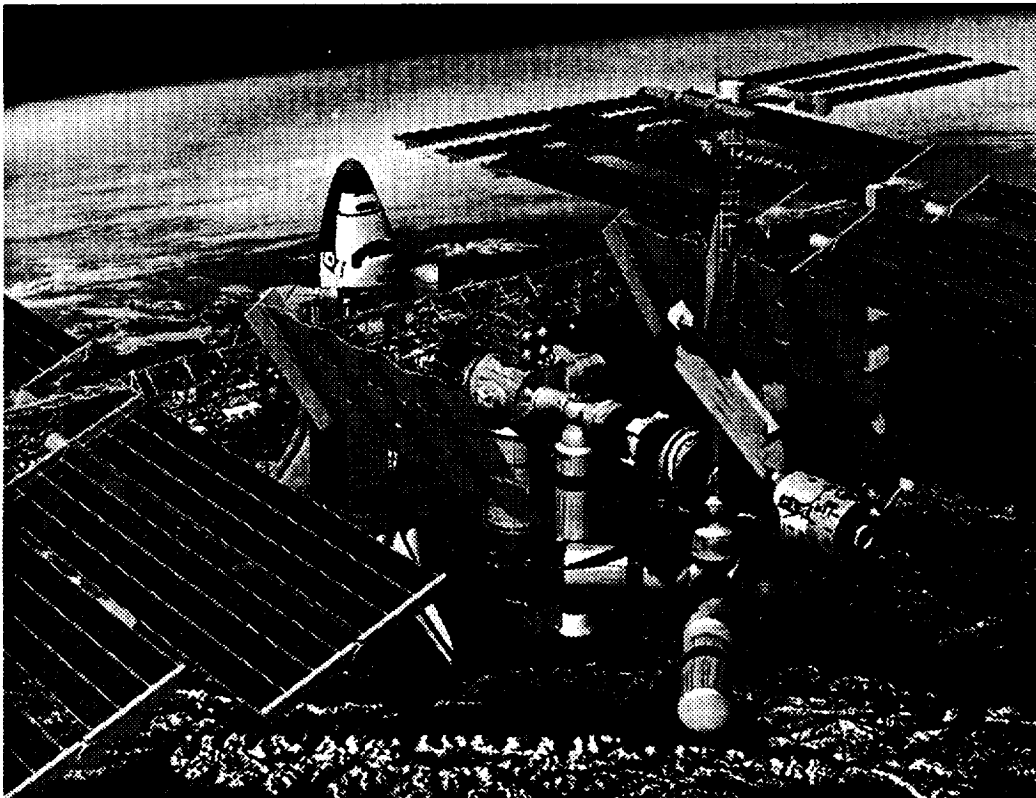
fashion. This integrated core takes the form of a detailed design of a **single modular rack** containing the requisite hardware and storage space, and an operating/examination table which is integrated with certain diagnostic hardware.

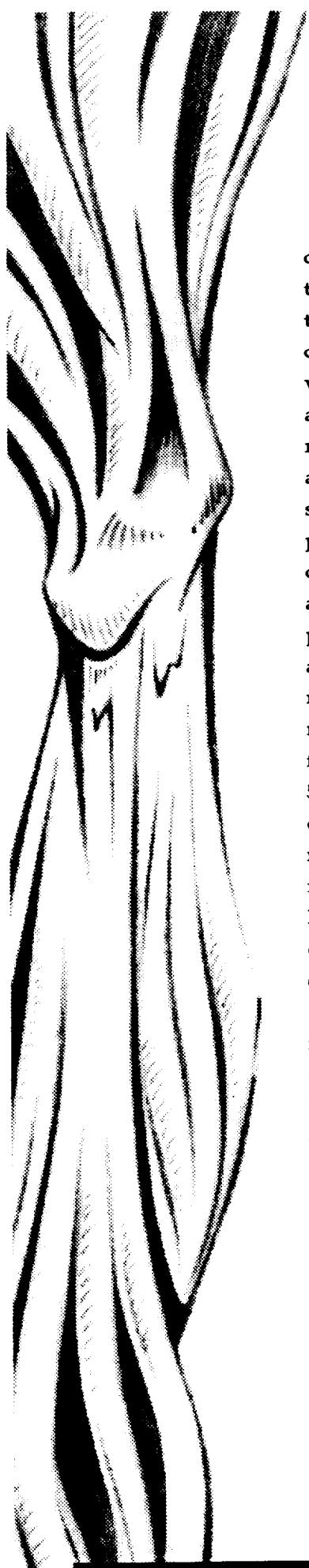
The adaptation of the equipment is mission specific and the layout of the operating facility will be decided on a number of grounds, including perhaps aesthetics and psychological factors. In twenty-five years time, launches may well be cheap enough to allow more indulgence in both the size and decor of space station and interplanetary vehicle modules than is currently tolerable.

CASE APPLICATIONS

SCENARIOS AND ENVIRONMENTS

To demonstrate the capabilities of the DOCC facility the report discusses its application to two scenarios, one for a low Earth orbit commercial space station and the second for a Mars mission. The two scenarios were selected as opposite extremes in terms of mission duration, level of gravitation, astronaut skill level, capability to return to Earth in emergency conditions, communication difficulties and the ability to resupply.





COMMERCIAL SPACE STATION

The use of microgravity conditions for the manufacture of innovative and important materials, as well as countless other applications, will ensure that space is used as both laboratory and factory in the future. It is envisaged that by the year 2015, sufficient demand will be in place to warrant a commercial space station able to accommodate up to 20 semi-professional astronauts (i.e. astronauts flying for commercial purposes and after a minimum level of training), for periods of between 2 and 5 weeks. Whilst in orbit, and due to the nature of the astronauts, a medical facility is required to maintain their health and performance, despite the hostile space environment.

Medical risk assessment, hardware and facility design are all covered within the report, combining the core components of the DOCC with the specific equipment required for such an orbital application. In addition, the ability to return the ill or injured astronaut to Earth rapidly via a crew rescue vehicle is addressed.

MARS MISSION

By the year 2020 human exploration of Mars will have started. The first precursor missions will probably be of short duration surface stays of perhaps 40 days, although later missions will increase the stay time to over a year. In such a situation the establishment of a permanent Mars base will support the crew during surface operations. With surface stays of around 400 days (combined with transit times of 300 days each way) the likelihood of medical problems cannot be ignored, and a highly capable medical facility is needed. The facility, whilst crewed by on-site doctors due to the communications delay, will need to be linked to Earth based consultants who will advise and assist during unforeseen situations.

To reduce repartition, it is proposed, at least for the early missions, to use the same medical facility on the surface as that used during transit. The transfer, which will be conducted under artificial gravity conditions will demonstrate the adaptability of DOCC core components to be able to cope with partial gravity situations. The heightened potential risks and increased duration of the Mars mission will lead to a greater range of medical



problems being encountered, and has resulted in an advanced design of the DOCC.

After addressing all the aspects of the core module and both case applications, legal and commercial aspects require a common assessment.

MANAGEMENT EVALUATION

POLICY AND LEGAL ISSUES

In addition to designing, manufacturing, and commercializing the DOCC, we also examine the political rationale behind governments participating in the project. Governments will want to participate and cooperate for several reasons. These reasons include: sharing project costs and risks, international and national prestige, potential spin-offs, and the advancement of earth and space medicine.

However the most compelling reason is to encourage more and longer manned space missions by providing a medical infrastructure (through the DOCC) that will provide comparable medical services and treatment in space as are available on earth.

Telemedicine is not a new medical discipline, but rather a new way of doing the same old thing. Therefore, many existing legal issues and regulations for practicing medicine can be applied to DOCC. Among these issues, liability and privacy issues must be addressed. The liability issues centre around individual and concurrent liability of the primary care provider (doctor aboard), that of the consulting physician (contacted via teleconference), that of the manufacturer, and that of the operator. Privacy rights of the professional and semi-professional astronauts





must be protected, since all their medical information will be collected and stored in electronic format on-board the remote facility, transmitted to the Ground Control Centre, and archived there.

Several organizations must be responsible for DOCC policy. It is anticipated that the World Health Organization (WHO), acting in an international advisory capacity, will standardise operating procedures and medical equipment for space medicine world-wide. An Intergovernmental Agreement must address ownership of intellectual property rights for innovations made by DOCC users, particularly since patent systems differ for the major space-faring nations.

BUSINESS ASPECTS

The DOCC product is defined as having three components: the DOCC hardware, the ground control service, and DOCC experimental capabilities. The competitive advantages of the DOCC product are its ability to adapt to a variety of environmental/industrial needs and the centralised/comprehensive nature of its support services.

Three groups of customers were distinguished: **governments, the private**

sector, and international non-profit organizations. It is important to recognise that insurance companies have a major influence in the customer's buying decision. There are two possible ways of approaching a pricing strategy: as a tangible hardware product and as a subscription for service. It is recommended to develop a promotion strategy based in terms of direct marketing and participation in international space related congresses, symposiums and exhibitions. Possible distribution channels for the product include the manufacturer, the sales force, and the service provider.

It is expected that both the government and the private sector will play a role in the initial phases of the development of the DOCC. Eventually the hardware and service segments of the DOCC will be completely privatised, and the DOCC and other developed technologies will be commercialised.

As a result of the costing exercise, the main cost drivers for the DOCC have been identified as follows: the development costs for designing a fully integrated facility embedded within a wider space system, the cost of adapting high technology medical hardware to space purposes, the transportation

costs, the insurance cost for transport and operation of the DOCC, the recurring costs of high technology items, the staff employed by the Ground Control Centre (GCC), the equipment acquired and installed in the GCC, the number of "in-air" users for each DOCC module, and the number of DOCC modules being supported by the GCC at a given time.

Different possibilities exist to lower the DOCC costs such as using existing space or terrestrial items, reducing the number of operation staff and adopting a risk sharing scheme between the involved parties.

CONCLUDING REMARKS

The preliminary design of the DOCC facility was completed and design recommendations and conclusions derived. The **main conclusions** resulting from the work were:

If the future exploration and exploitation of the boundless resources of the solar system are to be fully utilised, the need to promote and maintain the health of astronauts will be of paramount importance. In particular, as mission duration increases, greater importance will need to be placed on countermeasures and sup-

port of illnesses and injuries, and for this, a dedicated medical facility is essential.

In addition, as humans travel further away from their home planet and mission duration and communications delay expand, on-board doctors will be needed to provide a greater level of medical cover. To support this higher level of mission autonomy a dedicated training programme, such as the Space Surgeon Training Residency will need to be implemented.

Select-in criteria during the astronaut selection process, as currently practised in the Russian space programme, will become prominent to ensure that crew members will be able to handle the psychological and psycho-social pressures experienced during long term spaceflight.

Space surgery under micro and partial gravity conditions needs to be researched and performed as interplanetary missions become more common and patient evacuation is no longer possible.

As semi-professional astronauts start to fly into orbit for commercial purposes, their lower level of training may result in a higher number of medical problems being encountered. A basic DOCC facility will provide





the essential medical cover to cater for such situations and help facilitate the opening of the space frontier.

Development of a Medical Information System (MIS), integrating medical data in a computer based database, will lead to significant advances in medical knowledge and spin-off Earth applications of the technology.

It is believed that initially the major source of funding for the development and manufacture of the

DOCC will come from public sources. However, it is anticipated that as the number of applications and the number of DOCCs manufactured increases, privatisation will occur.

The most compelling political reason partner States would cooperate in the DOCC project is to provide an Earth like infrastructure in space for future manned missions.

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Introduction

Your loved ones were daring and brave, and they had that special grace, that special spirit that says, 'Give me a challenge and I'll meet it with joy'.

President Reagan's Speech on the Challenger Disaster (1986)

CALLING FOR A DOCC

A Dangerous Place

Space is a dangerous place for humans. Behind the carefree smiles of astronauts and cosmonauts, there lies a serious awareness that they risk their very lives in the name of discovery. Every passing week, they fly in exhilarating freedom, paying pounds of flesh and bone to the degenerative toll of microgravity. Every passing day, they perform experiments to expand the limits of knowledge, praying that the Sun will not suddenly strike them down in a rain of radiation. Every fleeting minute, they work tirelessly at peak efficiency to complete their mission successfully, often fighting the nausea and disorientation of space sickness. Every breath they take, they put their faith in their co-workers and their fragile spacecraft, gambling against the fatal consequences of error and failure, human and mechanical. In the light of all the danger, humans are the strongest and weakest link in space exploration. They carry the hopes and aspirations of entire nations. And they can be shot down by something as minuscule as a micrometeorite.

A Future Frontier

Space is a future frontier for a range of remote human habitats. The skies have already been, and will continue to be, overshadowed by space stations, from Salyut and Skylab, to Mir and International Space Station. A few days away, these orbital microgravity laboratories have been the homes of visiting astronauts and cosmonauts from numerous nations for many years. A week away lies the Moon, its mineral resources barely touched by humans. And half a year away awaits Mars, perhaps a former habitat of life. Whether the Red Planet still harbours life or not, plans are already underway to make Mars another remote human habitat. It took a decade to land a man on the Moon. Down the road for the next twenty years, visions of future human space activity promise to expand beyond low Earth orbit towards the Moon, and Mars.

From low Earth orbit, to the Moon, and to Mars, space is a new frontier beckoning pioneers, professional and non-professional, with a diverse range of opportunities. The human pioneer entering this frontier is the explorer, charting the unknown and establishing new remote human habitats. Another pioneer is the entrepreneur, seeking to exploit the unique properties of space to manufacture innovative products unheard of on Earth. The human pioneer is also the scientist, studying Earth from afar and how other worlds can teach us about Earth. And the politician has a role among the new pioneers, combining knowledge and resources to reach space by making new friendships with the other nations of the Earth.

For the Millions

Outer space, which only less than a century ago was the subject of dreams and speculation, is now used by millions of people all around the globe. During the short history of space exploration and exploitation thus far, both the actors in the field and the users of space technologies have evolved. In the early days, only governments were involved in the funding of large-scale space activities, and this was mostly due to national security interests as well as to the immense amount of moneys that were required. More recently, outer space is being exploited for daily commercial purposes, such as broadcasting, telecommunications, and geographic information systems (GIS). The players and consumers in these arenas are increasingly from the private sector, including universities and private individuals. Due to the exponential growth in the uses of outer space, existing policy and legal frameworks, which had their origins in a bi-polar non-commercial setting, must keep pace. The medical, legal, and political issues associated with long-duration human presence in space, when it is no longer sponsored by government agencies, must be addressed by any such framework. No longer is space the realm of test pilots, but of common men and women, and hence all the ensuing legal and policy concerns relevant on Earth must be dealt within their proper context in this new frontier.

Higher, Bigger, Longer

Already the rush to the new frontier has begun. From the blast-off of Gagarin, and the first small steps of Armstrong, to regular flights of Space Shuttle and the marathon stays on Mir, human activity in space is increasing. In the next decade, International Space Station promises even more human activity, with an unprecedented number of flights for construction alone. And in the future decades, the human undertaking to the Moon or to Mars would be even more enormous. Despite this rush, tomorrow's space pioneers continue to expand the frequency, duration, and complexity of human activity. In the range of remote habitats beyond the confines of Earth, however, space remains a dangerous place for humans. In fact, the danger, from effects like microgravity and radiation, *become even more immediate, more deadly, and* carry unknown long-term effects. It is up to another human pioneer, the space doctor, to continually guard against and study the threat of space to human health and performance. Help in space could only arrive after days, or weeks, or months, regardless of how desperate the cry for help may be. **The consequences for space medicine are enormous: namely the need to service more people, treat a greater body of physical and psychological threats, all of which are only beginning to be addressed today.** The doctor needs a medical facility to answer this cry for help immediately on-site. Such a facility could service different pioneers, from the explorer to the entrepreneur. And new medical technologies and innovations could be needed for each remote human habitat.

A Need for a Core Medical Capability

Despite technological advantages and innovations, much of general medical practice has remained constant over the centuries. Certain fundamental principles of medicine, such as the doctor-patient relationship and the "black bag" of basic diagnostic tools, could form a time-proven core medical hardware and procedural capability which can then be adapted to different environments. Applying this approach to space, **a core medical hardware and procedural capability** needs to be defined for general medical care in space. Traditional, fundamental principles can be combined with today's leading edge technologies, such as telemedicine, critical care medicine, and endoscopic surgery. This core capability can then be adapted to the special needs of a range of remote human habitats for current and future missions. An adaptable and proven core medical capability would permit rapid development of medical facilities for different environments, and ensure a degree of reliability and robustness. The doctor can then be armed with a proven set of flexible fundamental tools against the dangers of space.

This approach of tackling the space medicine problem, working from a general medical perspective, studying and establishing a foundation of medical functions and hardware that would be common to future space environments, is atypical of the space field, which is "mission-first". Not only has this approach never been explored, the medical, technological, operational, managerial, legal, and business requirements and implications, plus the interdisciplinary issues, for taking this "medicine-first" approach has

not been dealt with comprehensively. Furthermore, this entire “medicine-first”, interdisciplinary process, applied in the context of increased frequency, duration, and complexity of future human spaceflight, has never been fully addressed before. Until now.

MISSION STATEMENT

The goal of this project is to outline the design of the Distant Operational Care Centre (DOCC), a modular medical facility to maintain human health and performance in space, that is adaptable to a range of remote human habitats.

The purpose of this project is to outline a design, not to go into a complete technical specification of a medical facility for space. This project involves a process to produce a concise set of optimal requirements, addressing the fundamental problems and issues regarding the medical, design, operations, communications, transport, policy and law, and business aspects of a space medical facility for the future. The ideas presented here are conceptual, based on existing, researched, and hypothetical technologies. Given the long development times for space exploration, the outlined concepts from this project embody a collection of identified problems, and corresponding proposed solutions and ideas, ready to contribute to future space exploration efforts. In order to provide a solid extrapolation and speculation in the context of the future of space medicine, the extent of this project’s vision is roughly within the next two decades.

The Distant Operational Care Centre (DOCC) is a modular medical facility for space. That is, its function is to maintain human health and performance in space environments through prevention, diagnosis, and treatment. **Furthermore, the DOCC must be adaptable to meet the environmental requirements of different remote human habitats, and support a high quality of human performance.** To meet a diverse range of remote human habitats, the DOCC concentrates on a core medical capability that can then be adapted. Adaptation would make use of the DOCC’s modular functionality. **Functional modularity**, in this project, is the ability to replace, add, and modify core functions of the DOCC with old and new hardware, operations, and procedures. These challenges include what constitutes the core medical capability, and how DOCC can be adapted to different remote habitats.

Design Approach

The elements of the DOCC design process, as undertaken in this project, are as follows:

Formulate medical requirements

The DOCC consists of a core medical capability for space. The first step to designing such a core is to perform a medical risk assessment. The next

steps are: identify medical events, derive the medical requirements for future space environments, and determine appropriate means of prevention, diagnosis, and treatment for different patients' needs. Thus, a database of comprehensive expected space medical problems and solutions has to be assembled from bibliographic sources and medical expertise. These issues are addressed in Chapter 1 and Appendix C.

The medical requirements and the goal of an adaptable medical facility for remote human habitats drive what hardware would constitute the actual core medical capability. In order to achieve *functional modularity* for the future, it is the *function* served by the hardware which is emphasised, not the actual technical specifications of existing technology. The selection of hardware is discussed within the report.

Design core module

A collection of versatile medical hardware for foreseen medical problems cannot be adapted by itself. Integrating the selected hardware for the core medical capability into a cohesive *functional module* is the next step. This integrated whole, the **core module**, encompasses the core medical capability and the surrounding infrastructures of the design architecture, the space segment, the ground segment, and support services. This involves understanding the “big picture” relationships between the medical facility and the space and ground segments from a systems level, which are presented in Chapter 3. Chapter 4 shows the *conceptual and functional* architecture containing the core medical capability, the architectural drivers are to be outlined for the space segment along with communications aspects. Similar to Chapter 4, the ground segment is described in Chapter 5. Supporting the space and ground segments are the operations issues which are identified and detailed in Chapter 6.

Adapt core to case applications

To present how adaptable the DOCC is for a range of remote human habitats, and at what quality of performance, the core module design is adapted to two different case applications: *an orbital space station operated by commercial interests* (Chapter 7), and *a permanent international Mars base* (Chapter 8). Although project time constraints permitted only two case studies, the orbital and Mars applications offer a wide range of possible parameters against which to test the adaptability of the DOCC. Some of these parameters are summarised in the table overleaf. Chapters 7 and 8 discuss the details behind some of these parameters.

The commercial space station is anticipated to occur around the maturity of International Space Station (ISS), and before the first permanent Mars Base. Both cases are hypothesised to take place within the next 2-3 decades, especially in the light of the upcoming construction of ISS and the recent discovery of possible former life on Mars. Hence the selection

of the years 2015 and 2020 for space station and Mars base respectively. The selected years also allow for a reasonable and common time frame for extrapolation of existing and researched applicable technologies.

	Commercial Space Station	Mars Base (including transfer vehicle)
hypothesised mission year	2015	2020
number of personnel	20	6
number of doctors and medics on duty	1 doctor, 1 medic	2 doctors, 4 medics
anticipated number of patients at any one time	1 critically injured, 1 injured, 1 transported via rescue vehicle	1 critically injured, 1 injured
gravity	microgravity	0.38 g (on Mars and transfer vehicle)
typical mission duration	2-5 weeks	3 years

Table I.1 Case Application General Parameters

The contrast in number of personnel reflects the capacities of both cases. The commercial operation hypothesises the beginnings of big investment into space manufacturing and research, and hence a large arbitrary figure of twenty personnel. Six persons were chosen for the Mars case as it is a standard number used for NASA Mars exploration scenarios. The contrast of personnel numbers should create different challenges medically, technologically, and operationally.

The number of doctors and patients are a function of duration, transportation, and priorities. The space station case features relatively immediate access to the ground, with a shorter duration time in space. Hence, a lower proportion of anticipated doctors and patients with respect to crew size. With a mission to Mars, however, the high profile of such an international venture, the long duration times, and the impossibility of returning to Earth during an emergency demands a greater proportion of doctors to crew, and anticipates a greater proportion of patients to crew. The different gravitational conditions (microgravity in orbit, partial gravity on Mars) offered by both cases also affect the medical situation.

For the case of the Mars Base, the ISU '91 International Mars Mission, in addition to being a baseline, is used for any missing mission aspects in this report. Furthermore, it is assumed that only one DOCC will be used, which will be transferred from the transfer vehicle onto the Mars Base and

back again. This provides an opportunity for continuous maintenance, evaluation, and upgrade for the DOCC.

Identify business and legal issues and analyse policy

Regardless of case application, for the DOCC to be viable financially, commercially, politically, and legally, business issues and legal framework must be established alongside a government rationale. Chapter 9 assesses the DOCC's costs, identifies market potential of the DOCC's adaptability, shows the potential investors and customers, and gives directions to terrestrial commercial applications. Chapter 10 begins with several political reasons governments would co-operate on and fund DOCC. Furthermore, Chapter 10 studies the legal framework of existing law, highlighting the necessary issues the DOCC must resolve and what requirements it must comply with, and provides a reference for resolving potential future legal disputes.

Conclusions

In Chapter 11, the risks associated with the overall DOCC Design Project are identified and discussed. Suggestions are also made in order to minimise the risks. Chapter 12 contains recommendations based on unresolved issues and areas for future development of the DOCC. Due to the time constraints, a detailed analysis to identify critical parameters and design drivers could not be done. However, even with this limitation, the DOCC Design Project offers an enormous incentive for future medical care enhancements.

Section I

Medical Requirements

Chapter 1

Assessment of Medical Events

The purpose of medical capability on expeditions and in remote areas is to save the man, save the vehicle, save the mission, and save the scientific objectives, in that order of priority. The man must come first, as has been the tradition of medicine. However, it is a very unusual circumstance where any of the latter elements can be accomplished when any of the former ones have been lost.

Story Musgrave, MD

1.1 INTRODUCTION

Case History of the Future:

A 27 year old male astronaut on an extended Mars mission who is suspected of having a fracture of his left lower leg is brought to the DOCC for medical treatment.

While performing an EVA (Extra Vehicular Activity) to repair a faulty solar array on the Mars orbital station, the control manipulator arm he was using malfunctioned and crushed his leg against the outer wall of the space vehicle. His space suit was not punctured.

On examination by the on board medical personnel, the patient is found to be breathing rapidly, has a high heart rate and a low blood pressure. The patient

is very tender on the left lower leg and has a large swelling and blue discoloration in this area. Examination indicates no loss of blood flow or nerve function in the affected leg.

The patient has been in a microgravity environment for the past nine months. The patient states that he often “forgets” to perform his countermeasure exercises and so he is suspected of suffering from microgravity induced osteoporosis.

The patient is given medication for pain and is administered intravenous fluids. An X-ray is then performed and confirms a crushed left tibia and fibula.

The patient’s fracture is stabilised and then he is returned to the ground station on Mars where he receives surgery to fixate the bone. He remains on the surface of Mars where he is treated with medication and countermeasures. After four months, the patient has returned to duty on the orbital station, but is restricted from performing EVA’s.

During any expedition, including space expeditions, human health must always be the first priority. From the above scenario, clearly like an Earth environment, a variety of medical problems can occur in a remote space environment. A Distant Operational Care Centre (DOCC) must be prepared to treat any medical problem that can occur in a space environment. In addition, the DOCC should be capable of preventing medical problems before they occur.

In order to reduce the occurrence of medical events in a space environment, special selection criteria may be applied to astronaut candidates. Physiological and psychological evaluation of candidates is essential so that mission success is not compromised. This selection criteria is used to select-in candidates with the most suitable attributes to complete the mission and select-out candidates who have medical and psychological problems that make them unsuited for space missions.

In a space environment, the body goes through several changes to adapt to this new environment (e.g. the bones lose calcium when exposed to a microgravity environment). However, when the astronaut returns to an Earth environment, the astronaut’s body must immediately readapt. This sudden introduction to gravity can cause serious health problems if the astronaut does not perform countermeasures. Countermeasures may include exercises that must be done to reduce the consequences of the body’s physiological changes to the microgravity environment. In addition to physical exercises, various architectural design principles can be used to reduce psychological and physical problems that may occur. In the above case, the demineralisation of the astronaut’s bones may have been prevented if sufficient countermeasures were followed. This would have reduced the patient’s risk of having a fracture in the above case.

When a medical problem occurs in a space environment it must first be assessed. In the above scenario, the astronaut's physical condition was assessed by the medical personnel and was found to have a high heart rate, low blood pressure and a possible fracture. An X-ray confirmed the fracture. Space represents a unique challenge to medical practitioners because: 1) in addition to Earth medical problems, there is a unique set of medical events that can occur in space, and 2) the patient is far from conventional Earth medical centres. These problems may be overcome by using a computerised medical facility with artificial intelligence to aid in the assessment and treatment of patients and telemedicine links to provide expert advice from various physicians. In addition, physicians working in a space environment will require a specialised education program to prepare them for the unique diseases and conditions that may occur in a space environment. Virtual reality simulators will help medical personnel keep their skills current.

Treatments of some medical problems are very different in space in comparison to an Earth environment. For example, surgery in a microgravity environment requires that new methods be developed to maintain a sterile surgical area and keep the surgical area free of blood so that the surgeon can view the surgical area. Healing of fractures requires a gravity environment, and therefore the patient must either be returned to a gravity environment or artificial gravity must be created.

Hardware to treat medical problems must also be specially adapted to the unique diseases and environment that occur in space. For example, a conventional stethoscope may not be used on a noisy space station. Instead, an electronic stethoscope that filters background noise would be more useful to the medical personnel who are assessing the patient's heart beat. Also, the absence of gravity presents a unique obstacle that must be overcome.

This chapter will begin by assessing medical events that lead to medical problems that can occur in space. The process of crew selection, psychological problems and habitat design will also be discussed. Following this, physiological countermeasures will be presented.

When a problem occurs, the medical disease must first be diagnosed. This diagnosis may be made via a Computerised Health Maintenance System or via telemedicine. Once the medical problem has been assessed, it must be treated. Treatment of the medical problems may include pharmacological, surgical or dental treatment procedures. To conclude this chapter, the hardware required to treat the various medical problems will be discussed.

1.2 MEDICAL EVENTS

Medical problems arising in space may be divided into those resulting from the *occupational hazards* associated with the "job" of astro/cosmonaut, and those that occur independently of space activities. For example, during a spaceflight to Mars an occupational hazard is radiation that increases the probability of developing a fatal cancer during the lifetime of the crew

member. Other occupational hazards include microgravity, loss of pressure within the spacecraft or spacesuit, toxic substance release into the spacecraft, fire, excessive impact upon landing, Environmental Control & Life Support System (ECLSS, pronounced “ee-cliss”) failure, excessive noise, and dust contamination.

Primary medical events occurring in humans (as part of the inheritance of being human beings, but strongly influenced by diet and exercise habits) include vascular disease (heart attack and stroke), infections (by those ubiquitous beasts the bacteria, fungi, viruses, and protozoa’s), dental afflictions, skin diseases, gastro-intestinal ailments (those disorders more or less occurring along the length of the digestive tract from mouth to anus), psychiatric disorders, gynecologic disorders (the female reproductive tract), urinary tract disorders (kidneys and bladder), and neurological disorders. Indeed, virtually every part of the human body is potentially subject to a disease process. Much like an automobile, some parts wear out more commonly than others (brakes = lens of the eye), some parts we can tolerate the dysfunction of (squeaky brakes = callous on your big toe), and some parts we absolutely require (engine = heart). Fortunately, humans are remarkably well constructed and have a warranty developed over 3.5 billion years.

Astro/cosmonauts are certainly not immune to disease, although crew selection aims to minimise their frequency in successful candidates. Table 1.1 is an “Event Driven Analysis of Medical Problems Expected to Occur During Space Activities”, which comprehensively lists the medical problems that correspond to a particular event (either Occupational or Primary Medical). The countermeasures instituted to decrease the likelihood or severity of the medical problem, the medical equipment used to diagnose the presence or severity of the medical problem, the treatment, and the ground based element such as a medical doctor specialising in aerospace medicine are listed in Appendix C. Finally, any equipment mentioned in Appendix C, whether it be for countermeasures, diagnosis, monitoring, or treatment, is listed again in the “hardware” column of the same appendix to provide a complete hardware list for a particular medical event. A functional breakdown of the hardware is given in Appendix D, the Functional Hardware List.

The following example is taken from Appendix C. An occupational hazard in LEO (Low Earth Orbit) is microgravity, which results in loss of calcium from bone (bone demineralisation). Bone demineralisation is a physiological adaptation to microgravity that is benign until the crewmember returns to Earth gravity or is subject to torque and strains during EVA. Hence it is necessary to institute countermeasures to the physiological adaptation of bone demineralisation, namely aerobic and resistive exercise. In addition, aerobic and resistive exercises are a countermeasure to another physiological adaptation to weightlessness, namely loss of muscle mass (muscle atrophy). The medical diagnosis of bone demineralisation requires a device called a bone densitometer to measure the extent of bone loss (bone densitometry). Upon the decision of the Crew Medical Officer and the ground based medical

specialist who receives the data results of the bone densitometry, a medical treatment is formulated and put into effect.

In general, the medical problems associated with occupational hazards are more likely to occur than primary medical problems since the crew is medically screened for the latter. However, some occupational events such as puncture of spacesuit during EVA by a micrometeorite are vanishingly small, on the order of 10^{-6} to 10^{-8} , and therefore may be considered to be on a par with certain medical events such as a cerebrovascular accident (“stroke” or berry aneurysm [profound weakness in the wall of a blood vessel in the brain]).

Appendix C is intended to comprehensively address all the medical problems that could occur in most foreseeable space applications, and therefore makes certain key **Assumptions**:

- Crew Size = 3: This number is chosen because it is the smallest number necessary for a long duration mission to Mars. The total hardware requirements for a crew of three can be enlarged if a larger scale mission is conceived.
- Mission Duration: A multi-year trip to Mars is assumed so that the medical problems that might be absent or “silent” during a short duration mission would have time to develop and manifest over a long duration mission. Examples might include increased depression, increased muscle atrophy, increased exposure to radiation, and increased exposure to contaminants that accumulate within the spacecraft.
- Gravity dependent mission scenarios:
 - A) Microgravity: LEO and flight to Mars without artificial gravity.
 - B) Gravity: 1 g artificial gravity en route to Mars and 3/8 g on the Mars surface.

The Assumptions in One Sentence: Multi-year mission with crew size of three in both microgravity and gravity environments.

EVENT	MEDICAL PROBLEM
1. Microgravity (present during LEO)	1. <i>Bone Demineralisation</i> (bones lose their structural integrity and are therefore more prone to fracture) 2. <i>Muscle Atrophy</i> (most pronounced in the leg extensor slow twitch muscles: quadriceps, calf) 3. <i>Cardiovascular Deconditioning</i>: • orthostatic intolerance (upon return to Earth, gravity pulls blood into the legs and because of the already decreased plasma volume there is reduced perfusion to the brain) • size of heart decreases, therefore decreased ability to do work in EVA 4. <i>Nephrolithiasis</i> (kidney stones) 5. <i>Decreased Immunity</i> 6. <i>Fluid & Electrolyte Imbalance</i> (electrolytes are those ions in the blood and body fluids such as sodium, potassium, chloride, calcium, and phosphate) (An imbalance can lead to altered heart rhythm, altered nerve transmission, and potentially death.) 7. <i>Neurovestibular Deconditioning (NVD)</i> (decreased reliance on vestibular apparatus [inner ear balance organ] and increased reliance on visual cues) (NVD becomes a problem upon return to gravity environment.) 8. <i>Space Motion Sickness (SMS)</i> (nausea, vomiting, headache) (Onset is 3-5 hours post-launch and Duration is approx 2 days) 9. <i>Vitamin D deficiency</i> (exposure of the skin to direct sunlight is required for Vitamin D production in the skin) 10. <i>Musculoskeletal Injuries</i> • Back strain • Knee / ankle /wrist strain (especially in EVA) • Fractures: ⇒ crush fracture of fingers ⇒ stress fracture of leg bones (when ambulating on Mars surface)
2. Loss of Pressure • within spacesuit during EVA • within SC	1. <i>Decompression Disorders</i>: • Bends (classically termed Decompression Sickness (DCS) (nitrogen dissolved in the blood comes out of solution to form nitrogen bubbles in the tissues, particularly the joints) • Aeroembolism (air bubbles in the blood vessels due to rupture of pulmonary tissue.) (This is a serious form of Barotrauma - see below.) • Ebullism (exposure of body to pressure less than 47 mm Hg which is the vapour pressure of water at 37°C. In effect, the boiling away of body fluid.) 2. <i>Hypoxia</i> (decreased oxygen levels in the blood) 3. <i>Barotrauma</i> • ear block • sinus block
3. Toxic Substance Release: • propellants • coolants • payload chemicals	1. <i>Pulmonary Edema</i> (a serious condition in which the air sacs in the lungs fill with fluid and can no longer exchange oxygen with the blood.) 2. <i>Eye irritation</i> 3. <i>Mucous Membrane irritation</i> (irritation of the nose, mouth, throat, and airways of the lungs)

EVENT	MEDICAL PROBLEM
	4. <i>Skin irritation:</i> • contact dermatitis • chemical burns 5. <i>CNS disturbances</i> 6. <i>Cardiac arrhythmia</i> (abnormal electrical conduction in the heart) (example: cardiac arrhythmia may result from Halon 1301 used to extinguish fires)
4. Fire	1. <i>Burns</i> 2. <i>Smoke inhalation</i> 3. <i>Hypoxia</i> (decreased oxygen levels in the blood)
5. Impact (upon landing on Earth / Lunar / Mars surface)	<i>Trauma:</i> • lacerations • fractures
6. Environmental Control & Life Support System (ECLSS) Failure	1. <i>Failure of Carbon Dioxide Removal System:</i> Hypercapnia (elevated carbon dioxide level in the blood, leading to confusion and if continued unconsciousness and death) 2. <i>Failure of Air Revitalization / Air Supply System:</i> Hypoxia (decreased oxygen levels in the blood, leading to confusion and if continued then unconsciousness and death) 3. <i>Failure of Pressure Control System</i> (see EVENT: Loss of Pressure) 4. <i>Failure of Microbiology Control System</i> (leading to overgrowth of bacteria and fungi on SC interior surfaces and water supply): • Respiratory infections • Skin Infections • Eye Infections • Gastroenteritis (feeling of “upset stomach”, nausea, vomiting, diarrhea [causing depletion of fluids and electrolytes]) 5. <i>Failure of Particulate Matter Removal System I:</i> Foreign body in the eyes 6. <i>Failure of Particulate Matter Removal System II:</i> Foreign body in the lungs 7. <i>Failure of Trace Contaminant Removal System:</i> (see EVENT: Toxic Substance Release) 8. <i>Failure of Thermal Control System I:</i> Hyperthermia 9. <i>Failure of Thermal Control System II:</i> Hypothermia
7. Noise / Vibrations	1. <i>Sleeplessness</i> 2. <i>Decreased acuity of hearing</i> 3. <i>Psychiatric problems</i> (example: Noise may contribute to Adjustment Disorder)
8. Radiation	1. <i>Chronic low level radiation:</i> increased cancer risk 2. <i>Acute radiation exposure:</i> • Minor: nausea, vomiting, lethargy • Major: Decline / cessation of bone marrow production of red cells (leading to anemia and weakness) and white cells (leading to multiple infections), death
9. Dust Contamination	1. <i>Foreign body in the eyes</i> 2. <i>Airway / lung irritation</i> 3. <i>Skin irritation</i>

EVENT	MEDICAL PROBLEM
10. Nutritional / Metabolic	<i>Vitamin D deficiency</i> (exposure of the skin to direct sunlight is required for Vitamin D production in the skin)
11. Vascular (concerning the heart and circulatory system): • Atherosclerosis • Arrhythmia • Strokes	1. <i>Atherosclerosis</i> (deposition of fat and cholesterol in the wall of an artery causing a reduction in the diameter of the artery) which potentially results in: • Ischemia (lack of flow of blood to the heart because artery diameter is diminished) • Angina (pain felt in the chest due to ischemia of heart muscle cells) • Myocardial Infarct (ischemia to the point where heart muscle cells are so deprived of oxygenated blood that they die. This is a "heart attack".) • Congestive Heart Failure (the pumping action of the heart begins to fail, with the result that pressure within the blood vessels increases and forces some of the fluid portion of the blood into the lung's air spaces thereby reducing air exchange) 2. <i>Arrhythmia</i> (abnormal electrical conduction in the heart) which may be associated with EVA activity and LBNP (Lower Body Negative Pressure countermeasures for cardiovascular conditioning - see EVENT: Microgravity)
12. Infectious Disease	3. <i>Cerebrovascular Accident (CVA)</i> ("Stroke") (permanent or transient loss of blood flow to the brain with permanent or temporary neurological deficits) 1. <i>Respiratory infections</i> 2. <i>Skin infections</i> 3. <i>Eye infections</i> 4. <i>Gastroenteritis</i> (feeling of "upset stomach", nausea, vomiting, diarrhea [causing depletion of fluids and electrolytes]) 5. <i>Urinary tract infections</i> (typically these are bacterial infections of the urinary bladder)
13. Dental	1. <i>Caries</i> (tooth cavity requiring a filling / extraction) 2. <i>Fractured tooth</i> 3. <i>Laceration of soft tissue</i> 4. <i>Cracked tooth or cusp</i> 5. <i>Pulpitis</i> (inflammation of the pulp cavity containing nerves and blood vessels of an individual tooth) 6. <i>Periapical abscess</i> (infection around the tooth)
14. Surgical	1. <i>Wound</i> 2. <i>Surgical abdomen</i> (appendicitis, cholelithiasis [gall bladder stones], certain gynecologic conditions)
15. Skin	<i>Contact Dermatitis</i>
16. Gastrointestinal	1. <i>Gastroenteritis</i> (feeling of "upset stomach", nausea, vomiting, diarrhea [causing depletion of fluids and electrolytes]) 2. <i>Peptic Ulcer Disease (PUD)</i> (the lining of the stomach is eroded by stomach acid) 3. <i>Erosions</i> (less intensive erosion than an ulcer) 4. <i>Others:</i> • Cholecystitis (infection of the gall bladder) • Irritable Bowel Syndrome • Pancreatitis
17. Gynecologic	<i>Menorrhagia</i> (excessive menstrual flow in females)

EVENT	MEDICAL PROBLEM
18. Genito-Urinary	1. <i>Prostatitis</i> (infection of the prostate gland) 2. <i>Cystitis</i> (infection of the urinary bladder) 3. <i>Pyelonephritis</i> (infection of the kidney)
19. Ophthalmic	1. <i>Acute glaucoma</i> (an increase in pressure inside the eyeball which compresses blood supply to the optic nerve, potentially causing blindness if untreated) 2. <i>Iritis</i> 3. <i>Complicated fungal and bacterial Infections leading to corneal ulceration</i>
20. Psychiatric	1. <i>Major Affective Disorders</i>: •Major Depression •Bipolar Disorder (Manic Depression) 2. <i>Psychotic Disorders</i> 3. <i>Adjustment Disorders due to</i>: •Isolation and Confinement •Stress

Table 1.1 Event Driven Analysis of Medical Problems

1.3 CREW SELECTION

1.3.1. Introduction

A proper selection of crew members is essential to ensure mission success, performance, and crew safety. Well-designed selection and training programs are crucial prerequisites for the successful completion of manned space flight.

Physiological and psychological evaluation of astronauts will become more critical as missions become longer. Aspects of operational needs and crew skills are also essential.

International crews will be more likely in future space flight scenarios; therefore, group-selection and cross-cultural training is a must in crew composition.

A basis for present and future crew evaluation is to make an analysis of medical data from prior space flights. Also, longitudinal records from the annual astronaut health-check are examined to see why difficulties in previous flights arose and to determine possible effective countermeasures.

1.3.2 Medical Selection

Candidates for astronaut selection are medically evaluated, using principles and techniques of preventive medicine which rule out serious medical risk factors and identify those individuals with maximum career potential. The system for medical evaluation employs modern diagnostic and evaluation procedures to point out candidates whose current state of health is exceptional, and whose long-term health prospects are excellent.

The predictability of these evaluations has been verified against medical screenings and many years of operational aviation and space medicine [Billica, et al., 1996].

It is essential that persons with chronic diseases, malfunctions of body systems and impairments which could have influence on mission success are excluded from space flight. The selection process also helps to find people with reliable resistance against diseases and injuries which can occur during manned space flight [Atkov, 1996].

Medical problems which may occur during manned space flight include:

- Skin: dermatitis, pyoderma, ecchymosis, minor laceration.
- Haematology: anaemia, bone marrow suppression.
- Ear, Nose and Throat: acute diseases and traumatic states, chronic tonsillitis.
- Eye: acute diseases and trauma, foreign body.
- Dental: jaw fracture, caries, pulpitis.
- Musculo-Skeletal-System: dislocation, fractures, bruises, arthritis, myositis.
- Central Nervous System: neurotic states, emotional disorders, radiculitis, psychotic disorders, insomnia, cranial or spinal trauma.
- Cardiovascular System: angina, myocardial infarction, unstable blood pressure, arrhythmia, non ischemic chest pain.
- Pulmonary System: bronchitis, pneumonia.
- Gastro-Intestinal-System: cholecystitis, appendicitis, constipation, diarrhoea, gastric/duodenal-ulcers, gastro-entero-cholitis.
- Genitourinary System: urethritis, cystitis, prostatitis, renal calculi
- Allergic reactions: drugs, food, environment.
- Toxic and Radiation
- Infections
- Neoplasm

Astronaut-candidates are specially screened to select-out persons who are highly susceptible to these diseases. Also the medical history of near relatives of the candidates are investigated. The evaluation is performed by surveying the medical history and by physical and laboratory examinations.

The medical evaluation for astronaut selection should address :

- | | |
|-------------------------|------------------------|
| 1. Medical history | 4. Dental |
| 2. Physical examination | 5. Ear, Nose, Throat |
| 3 Laboratory: | 6. Ophthalmologic |
| A. Haematology | 7. Neurological |
| B. Blood chemistry | 8. Genito-Urological |
| C. Urine | 9. Cardiopulmonary |
| D. Faeces | 10. Psychiatric |
| E. Endocrine | 11. Radiation exposure |
| F. Radiological | 12. Musculoskeletal |
| G. DNA-Screening | |

All selected astronauts are carefully monitored for years (annually) before and after the mission in order to evaluate the original selection process and improve it for the future. Knowledge of the diseases astronauts develop in their lifespan helps to further adapt selection and treatment.

1.3.3 Psychological Crew Selection

Crew selection is a vital component of the Crew Psychological Support System (CPSS) within the Distant Operational Care Centre. Experience from long-duration spaceflights and space-analogue environments has demonstrated the ability for psychiatric, psychological and psychosocial stressors to adversely affect crew performance [1-18].¹ Strong technical skills, excellent health, and absence of psychiatric illness alone are insufficient to ensure effective crew performance for an extended-duration mission on a Mars base [19].

In addition to the medical criteria used in current selection procedures, crew selection for the manned Mars base or an extended stay on the commercial orbital facility will require the development and use of stringent psychiatric and psychological selection criteria [20].

The benefit of using *psychological selection criteria* for the selection of crews operating within isolated, confined, and extreme environments such as spaceflight has been demonstrated in several space simulation studies [90, 100]. In one such study, a four-member experimental crew was confined in a submarine for a 60-day period. Crew members were selected for participation after a stringent psychological selection process including assessment of emotional stability and compatibility, and participation in an intensive eight-week “social sensitivity” training program. Results showed no decrements in crew motivation, morale, or interpersonal relations. An alternate study in which no selection or training procedures were employed for the participating crew members resulted in a significant increase in the negativity, frustration and irritation level of individual crew members (directed towards each other

¹ Numbered references in Sections 1.3 and 1.4 appear in Appendix F

as well as outside personnel), in addition to a significant decrease in mood [100]. Such studies in combination with others clearly illustrate the importance of implementing psychological selection and training procedures for crews operating within such environments.

1.3.3.1 Psychiatric Selection Criteria

Psychiatric selection criteria will be used to *select-out* individuals possessing any pre-existing, present, or predisposed tendencies for future psychological or psychiatric disorders. Such disorders include depression, psychosis, schizophrenia, neurosis, personality disorders and emotional disorders of any kind. The psychiatric selection criteria developed by the Russian and United States space programs to date have been successful in identifying and selecting-out candidates with psychiatric illnesses. Accordingly, these criteria will continue to be utilised.

1.3.3.2 Psychological Selection Criteria

Psychological selection criteria will be developed to *select in* individuals with attributes found to be optimal for withstanding the effects of long-duration spaceflight. Current psychological assessment methods include personal interviews and evaluations, performance tests, personality questionnaires, projective techniques, and biographical data evaluations [94]. The development of a more comprehensive body of knowledge regarding the psychological criteria most appropriate for selecting individuals for extended-duration spaceflight needs to begin with a thorough examination of all empirical research examining the psychological, psychosocial, and psychiatric stressors characterising the spaceflight environment. A research program aimed at increasing the breadth of this knowledge will thereafter begin. Additionally, behavioural and performance data generated from the CPSS Research Platform (discussed in Section 1.4) will be integrated into future selection criteria.

1.3.3.3 Psychosocial Selection Criteria

Studies have demonstrated that enhancing *crew* compatibility should be an important part of the selection and training protocols for extended-duration spaceflights [93]. Interpersonal problems can affect the ability for crew members to effectively work together, thereby possibly leading to decrements in team performance [29]. Candidates possessing the attributes complimentary to efficient team performance and interpersonal functioning, along with the necessary technical, medical, psychiatric, and psychological attributes, will be *selected in*. Procedures for developing psychosocial selection criteria will follow those presented for the psychological select in criteria discussed above.

1.3.3.4 Unit of Selection

Long-duration missions impose significant demands on crews for high-level team co-ordination and performance. Correspondingly, experiences from spaceflight [95] and analogous environments [50, 96] suggest that *entire crews* should be selected, rather than individuals, in order to ensure good crew

performance and a high level of group cohesiveness, as well as to minimise crew workload resulting from interpersonal conflicts [30, 45, 97, 98, 99]. Based on these recommendations, candidates selected for the Mars base according to technical, medical, psychiatric, psychological and psychosocial criteria, will then be selected into a specific mission crew.

1.3.3.5 Conclusion

The ability for crews to successfully operate within the permanently manned orbiting space station facility and the Mars base depends on our ability to successfully select individual crew members and crews appropriate for withstanding the stressors of the long-duration spaceflight environment. Utilisation of existing research, the development of programs aimed towards supplementing areas lacking in empirical research, and implementing feedback from the Crew Psychological Support System Research Platform (discussed in Section 1.4) into the selection process will provide an aggressive and effective program for increasing mission success.

1.4 CREW PSYCHOLOGICAL SUPPORT SYSTEM (CPSS)

1.4.1 Introduction

Advances in science and technology during the few years preceding the third millennium have truly entered humankind into a new age of exploration and challenge. These explorations have allowed humans to grasp the heavens and to dive the depths, and consequently, to challenge the limits of our scientific and technological capabilities. Yet these challenging endeavours often remove humans from their protective envelope and, in doing so, push the limits of human abilities farther than ever before. As one prepares to embark on an extended duration, internationally crewed space mission, at no other time will the understanding of human performance and behaviour be so vital to the successful undertaking of such a endeavour. The application of scientific efforts in the areas of human performance and behaviour including psychiatry, psychology, crew performance, and human factors are crucial in addressing issues of crew selection, training, performance, and ultimately, mission success.

The ability for human crews to successfully operate in the proposed permanently-orbiting space station and Mars base environments depends on the ability to adapt these crews to the significant psychological, psychosocial, and human-technology and environmental interface stressors characterising these environments. The Russian experience shows that for missions greater than one year in duration, the principal problem, once the primary biomedical life support problems are countered, is the interpersonal dynamics among crew members and the maintenance of crew performance [35, 36]. As a vital component of the DOCC, the *Crew Psychological Support System (CPSS)* is tasked with supporting these aspects of flight.

The *Crew Psychological Support System (CPSS)* within the DOCC is tasked with supporting all aspects of crew psychological health and performance in all phases of flight (pre-flight, in-flight, and post-flight), through proper crew selection, training, and support. For all missions, the CPSS must provide the following:

- psychological countermeasures for all factors identified which degrade crew performance and behaviour;
- the capability of assisting the crew physician(s) in identifying, diagnosing, treating, and monitoring all psychological and psychiatric conditions;
- the ability to serve as a platform for conducting research and scientific experiments to assess all psychological and psychiatric effects of spaceflight;
- training and support measures for optimising crew performance and facilitating crew adaptation to the stressors of spaceflight;
- a Crew Psychological Support Team (CPST) responsible for supporting all aspects of the CPSS and crew psychological health and performance;
- development and implementation of spacecraft habitability guidelines;
- psychological, psychiatric, and psychosocial selection of spaceflight crews.

A review is now offered for the *psychological*, *psychosocial*, and *human-technology* and *environmental interface* stressors characterising the spaceflight and space-analogue environments, followed by a description of the CPSS and its objectives, capabilities, and hardware requirements. Habitability issues which are considered part of the CPSS are addressed in Section 1.5 of this chapter. Numbered references included in the body of this report, as well as in the accompanying tables, may be found in Appendix F.

1.4.2 The Spaceflight Environment

Characterised by temperature extremes, microgravity, solar and galactic cosmic radiation, lack of atmospheric pressure and high-speed micrometeorites, the spaceflight environment is hostile in nature and lies well beyond the envelope containing the necessary elements for supporting and maintaining human life. Historically, efforts by manned spaceflight programs have been primarily dedicated towards providing the engineering hardware and life-support systems necessary for withstanding these extremes and sustaining human life in this hostile environment. As progress is made in the ability to successfully provide these technological and scientific capabilities, however, efforts are being increasingly allocated towards supporting and optimising the *human performance* aspects of flight.

While the spaceflight environment poses significant technological and physiological challenges to the crews operating within it, extended duration flights have brought forth a new set of challenges related to human performance and crew factors. Critical incidents relating to the psychological, behavioural, and interpersonal aspects of crew performance have, at times, jeopardised crew safety and mission success since the beginning of human spaceflight in both the Russian and United States Space Programs [1-18]. Such incidents have called attention to the importance of these issues as they represented significant potential for decreased crew performance and mission success [19-26]. Research from analogue environments has demonstrated the tendency for such incidents to increase in frequency and magnitude with increased mission duration and cultural diversity [27-33].

The psychological, psychosocial, and human performance aspects of spaceflight have taken on increased importance as mission operations require greater stays in the space environment and crews become more heterogeneous as to multinational factors, experience, professional background and assigned duties [34].

Adding validity to these concerns is a recently conducted study in which sixty space medical experts were asked to assess their perception of the probability of nine different categories of medical problems occurring in spaceflight. Of these, the category with the second highest perceived probability of occurrence was that of *mental disorders* [37].

1.4.3 Stressors in the Spaceflight Environment

The spaceflight environment is characterised by a myriad of human stressors including *physiological, physical, psychological and psychosocial stressors*. These stressors arise from interactions between the *human-environmental*, *human-technology*, and *human-human interfaces* characterising the spaceflight environment, and have direct implications for the health and performance of all space crews. Table 1.4 includes a comprehensive listing of the myriad of stressors characterising the spaceflight environment.

1.4.3.1 Physiological and Physical Stressors

Physiological and physical stressors may be classified into two categories: those relating to the *human-spacecraft* interface and to the *human-environmental* interface. The *human-spacecraft interface* describes the interface between all physical properties of the spacecraft and the crew member. The *human-environmental interface* describes the interface between the environmental factors present in space and the crew member. Stressors falling within each category are illustrated in Table 1.2.

The human-technology interface poses significant opportunities for decrements in human behaviour and performance in the spaceflight environment. Results from a thirty day space simulation study designed to assess a manned environmental system revealed that *inadequate equipment*

design contributed substantially to the irritation and vexation of the crew [90].

Human-spacecraft interface	Human-environmental interface
acceleration	radiation
vibration	altered circadian rhythms
noise	altered time-parameters
lighting and illumination	decreased exposure to sunlight
adaptation to artificially engineered environment	physiological and physical adaptation to microgravity
anthropometric design	food (quality, variety and aesthetic quality)
personal hygiene and maintenance facilities	sensory and perceptual deprivation
habitability	***
design of hardware, instrumentation, displays, living facilities	cabin atmosphere (temp., humidity, composition, aesthetic quality)

Table 1.2 Physiological and Physical Stressors in the Spaceflight Environment

1.4.3.2 Psychological Stressors

The Russian space program has extensive experience in extended-duration spaceflight operations and has acknowledged that long-duration flight is quite different from short-duration in that the effects on human performance and behaviour are magnified [36]. This experience has resulted in the identification of a set of psychological symptoms consistently experienced by extended duration flight crews, referred to by Russian specialists as *Astenic Syndrome* [36] (see Table 1.3).

Astenic Syndrome
1. feeling of tiredness
2. emotional instability
3. sleeplessness
4. sharpening of personality
5. incapacity for work
6. disruption in psychophysiological reaction
7. psychosomatic dysfunction

Table 1.3 Characteristics of Astenic Syndrome

The psychological stressors playing a significant role in affecting crew behaviour and performance, particularly in long-duration flight, are listed in Table 1.4.

1.4.3.3 Psychosocial Stressors

Collet et al. [38] assert that interpersonal relations between crew members will be the *primary* limiting factor for long-duration spaceflights. Psychosocial stressors existing in the spaceflight environment are illustrated in Table 1.4. Relating to psychosocial aspects of crew performance in spaceflight, Santy et al. [39] conducted an international shuttle crew debrief on the impact and number of pre-flight, in-flight, and post-flight incidences related to

multicultural factors. Results showed that for nine U.S. astronauts who flew on international space missions, forty-two incidents were reported (nine during pre-flight, twenty-six in-flight, and seven in the post-flight period.) Astronauts rated the majority of these incidences as having low or medium impact, but five of the in-flight incidents were rated as having a high mission impact. Such incidents are indicative of the importance of multicultural factors in maintaining performance for crews on the Mars base.

1.4.4 Space-Analogue Environments

Continual expanses in technology and scientific capabilities have allowed humans to work and explore in environments which greatly challenge their capabilities. While these environments offer the capability of exploring the limits of technology, they offer an exceptional capability of exploring the limits of human performance and behaviour as well. Environments posing such challenges include spaceflight, undersea laboratories and submarines, Antarctic and Arctic stations, and off-shore oil platforms. Referred to as *isolated and confined environment's* (ICE's), many share a variety of characteristics posing considerable challenges to the crews working and exploring within them.

Psychological Stressors	ENVIRONMENT			
	Spaceflight	Polar Stations	Submarines	Simulators
Confinement	x	x	x	x
Isolation	x	x	x	x
High risk/threat of danger	x	x	x	
Limited possibility for mission abort	x	x	x	
Mission parameters: duration, complexity, danger	x	x	x	
Alterations in sensory stimuli	x	x	x	
Limited facilities, equipment, supplies	x	x	x	x
Hostility of the external environment	x	x	x	
Heavy reliance on human-technology interface	x		x	
Physiological/physical adaptation	x	x	x	
Absence of natural time parameters	x	x	x	x
Limits on exchange of information and communications from the external environment	x	x	x	
Psychosocial Stressors				
high proximity and frequency of human-human interaction	x	x	x	x
Interpersonal tension	x	x	x	x
Differing personalities, values, and motivations of crew	x	x	x	x
Crew factors : (gender, size, multiculturality, heterogeneity)	x	x		x
Leadership and role structures	x	x	x	x
High crew co-ordination demands	x	x	x	x

Table 1.4 Stressors in the Spaceflight and Space Analogue Environments

Because of the similarities these environments share with the spaceflight environment (Table 1.4), they have been instrumental to researchers and scientists for developing an understanding of the factors affecting human performance in a variety of stressful environments. A careful review of these studies has isolated a number of psychological, psychiatric, and interpersonal issues relevant for long-duration spaceflight [29].

While differences between ICE's exist, along with limitations in the ability to apply research findings directly from one environment to another, findings from one environment can often be applied with caution and selectivity to another in order to allow an understanding of the human behaviour and performance to be expected in such environments. It is generally accepted that despite these limitations, research from analogues provide convincing evidence about the kinds of behavioural issues that affect crew performance and health on extended duration spaceflights [28].

1.4.5 Effects of Space and Space-Analogue Environments

Studies of the effects on human behaviour and performance in isolated and confined environments such as Antarctic stations, submarines, and simulators have demonstrated deficits in the psychological, cognitive, and psychosocial functioning of the crew members operating within them. These effects can be classified into several categories including somatic, psychological, psychosocial, psychiatric, and cognitive. The most common physical and emotional symptoms observed in Antarctic stations and submarines are aggression, sleep disturbances, depression, and anxiety. A comprehensive listing of the behavioural effects experienced by crews operating in space and analogue environments is illustrated in Table 1.5. Many studies on isolated and confined environments suggest that as mission duration increases, the probability of these behavioural problems and dysfunctions increase [40].

1.4.5.1 Somatic Effects

Somatic symptoms refer to physical or bodily symptoms such as headaches, chest pain, increased heart rate, stomach problems, and muscle aches. Relatively common correlates occurring among space, polar, submariner, and simulation crews include a variety of somatic complaints. Other somatic effects experienced in response to isolation and confinement are illustrated in Table 1.5. It is generally accepted that these findings do not simply reflect unappetising food rations, cramped sleeping quarters, or extreme conditions; there is presumed to be a fairly strong psychological component contributing to these symptoms as well [40].

1.4.5.2 Psychological Effects

Mild psychiatric symptoms associated with extended stays in isolated, confined, and extreme environments have been reported with considerable consistency [40]. The most common include depression and anxiety. Other symptoms observed are included in Table 1.5.

ENVIRONMENT					
EFFECTS ON PERFORMANCE	Spaceflight	Antarctic	Submarines	Simulators	Citations
Psychological & Psychiatric					
reduced motivation, vitality, work satisfaction	x	x	x	x	[33] [36] [40] [54] [55] [56] [83] [84] [90] [91] [93]
boredom	x	x	x	x	[40] [60] [78] [81] [90] [91]
emotional instability	x	x			[36] [79]
depression		x			[54] [57] [58] [59] [62] [66] [67] [92]
anxiety		x			[56] [67] [68] [93]
Somatic effects					
headache		x	x		[40] [55] [57] [65] [77]
sleep disturbances	x	x	x	x	[36] [40] [54] [55] [57] [59] [62] [63] [64] [91] [92]
fatigue	x	x		x	[36] [58] [89] [92]
stomach/digestive problems	x	x	x		[57] [64]
increase in psychosomatic responses	x				[36] [74]
Cognitive					
impaired alertness, concentration, & memory		x			[62] [66] [69]
perceptual distortions/alterations					[36] [80] [81]
Psychosocial & Interpersonal					
displacement of anger to outside personnel	x	x	x	x	[2] [4] [17] [70] [71] [14] [81] [85] [90] [93]
decreased team cohesiveness	x	x	x	x	[22] [30] [72] [73] [74] [76] [82] [83] [84] [85] [93]
increased need for privacy		x		x	[29] [90]
touchiness, interpersonal conflicts & social irritability	x	x	x	x	[33] [47] [20] [22] [54] [57] [58] [59] [60] [61] [72] [73] [75] [83] [84] [90] [91] [92] [93]

Table 1.5 Effects of Spaceflight and Space-Analogue Environments

1.4.5.3 Psychosocial Effects

Psychosocial effects observed in spaceflight as well as in analogue environments are outlined in Table 1.5. A common finding among crews operating in hostile, isolated and confined environments is the tendency for communications between crews and ground controllers to be strained, irritable, and at times, even hostile [2, 4, 17, 70, 71, 14, 81, 85, 90, 93].

Crew performance can be affected by a myriad of factors including crew composition (i.e., gender, age, nationality, professional status, military rank), crew size, the amount and type of training, the experiences they share before the mission, and by the specific mission circumstances under which they interact [41]. Psychosocial and interpersonal factors will play a crucial role in the success of crew performance on all future, extended-duration spaceflights [35, 36, 38].

1.4.5.4 Cognitive Effects

There is some evidence that extended stays in isolated and confined environments lead to impaired intellectual and cognitive functioning [36, 40]. Examples of such effects can be found in Table 1.5. To date however, the majority of studies examining cognitive functioning in ICE's have *not* demonstrated significant decrements. These findings suggest that the decrements in performance and functioning so commonly found in empirically based studies of human performance in space and space-analogue environments can be attributable primarily to behavioural (psychological, psychosocial, and human factors, {mismatches in human-technology and human-environmental interfaces}) rather than cognitive factors.

1.4.5.5 Psychiatric Effects

Psychiatric effects from extended exposure to isolated and confined environments include *anxiety, depression, psychosis, and somatic symptoms* [29]. A study by Rasmussen and Haythorn [42] indicated that the number of anxiety episodes during a polar winter-over increased from three during the first four months to eight during the next four months and nineteen during the last four months. The corresponding figures for suspicious episodes were zero, seven, and sixteen, and for periods of uncooperativeness, one, two, and thirteen. Such findings are consistent with others which illustrate the increased effects of psychological and psychiatric stressors as mission duration increase.

1.4.6 CPSS System Description

The CPSS within the DOCC is tasked with supporting all aspects of crew psychological health and performance through all phases of flight (pre-flight, in-flight, and post-flight). The manned Mars base which the DOCC is tasked with supporting will involve significant degrees of isolation, confinement, and risk rarely equalled by any environment on Earth [40]. For this mission to Mars as well as an extended-duration Earth-orbiting mission, the CPSS must provide:

- psychological countermeasures for all factors identified to degrade crew performance and behaviour;
- the capability of assisting the crew physician(s) in identifying, diagnosing, treating, and monitoring all psychological and psychiatric conditions;
- the ability to serve as a platform for conducting research and scientific experiments to assess all psychological and psychiatric effects of spaceflight;
- training and support measures for optimising crew performance and facilitating crew adaptation to the stressors of spaceflight;
- a Crew Psychological Support Team (CPST) responsible for supporting all aspects of the CPSS and crew psychological health and performance;

- psychological, psychiatric, and psychosocial selection of spaceflight crews.

1.4.6.1 Liveware

The components required to carry out all CPSS functions in the DOCC include hardware, software, and liveware.

Liveware refers to the personnel or human operators (i.e., flight physicians, psychiatrists and psychologists) necessary to carry out all responsibilities and functions of the CPSS. The primary component of the CPSS Liveware is the Crew Psychological Support Team (CPST). The CPST consists of a support team including the crew physician, psychiatrist, and psychologist with whom the spaceflight crew have trained. This team's objective is not to critically *evaluate* crew performance, but rather to *support* the flight crew in all phases of mission operations from training through post-flight with the objective of maintaining health and performance. Thus, the CPST will:

- support crew psychological health and performance through all phases of flight (pre, during, and post);
- provide crew training and pre-flight, in-flight, and post-flight psychological support to all crewmembers and their families;
- administer, maintain, and analyse data derived from the CPSS Research Platform;
- develop all psychological countermeasures, psychological selection criteria, training, and support procedures;
- identify and select crew candidates with the psychological and psychosocial capabilities needed to withstand the stressors of spaceflight (select-in) and identify individuals with previous, present, or predisposed tendencies for future psychological and psychiatric conditions undesirable for flight (select-out);
- provide crews with access to continual psychological and social support in a variety of forms (i.e. continual access to the Crew Psychological Support Team, electronic-mail communication capabilities, virtual reality aids, visual and auditory communications with family and friends);
- act as liaison between crew and ground control when communications are strained;
- develop and assure implementation of spacecraft habitability guidelines;
- develop protocols for coping with crew behavioural and performance problems likely to occur in flight.

It is critical that behavioural problems occurring within flight crews not necessarily be viewed as “deviant behaviour.” In environments not characterised by such pronounced stressors, such behaviours may be referred

to as deviant, however, in the hostile conditions of long-duration spaceflight it is suggested that these behavioural effects be viewed *within* the normal range of behaviour expected for such conditions.

1.4.6.2 Hardware

Hardware refers to all the equipment and supplies needed to support the CPSS and consists of:

- medical instrumentation and imaging equipment capable of identifying and diagnosing any psychiatric or psychological anomalies occurring in flight.
- a laptop computer system capable of: (1) assisting in the identification and diagnosing of mental anomalies, as well as (2) supporting the battery of tests used for assessing the effects of spaceflight on crews.
- computer software necessary for administering and storing cognitive, psychological, psychophysiological and psychosocial experiments used for documenting and analysing the effects of spaceflight and microgravity on crew performance and behaviour.
- communication equipment supporting private two-way audio and visual capabilities between the crew and ground. (The importance of allowing *video* teleconferencing capabilities as opposed to audio-only capabilities is evidenced by research illustrating the ability for audio-only communication to exacerbate interpersonal conflict and decreased crew task performance [86, 87, 88]).
- a Psychopharmacological Supplies Kit to be used in the treatment of acute behavioural disturbances due to anxiety, stress, psychosis, sleep disturbances and depression or any other psychological condition which may compromise crew safety and health. The Psychopharmacological Supplies Kit includes a variety of pharmaceuticals for treatment of any psychiatric, psychological, or behavioural disorders experienced in flight.
- a crew restraint system capable of providing an effective means of restraining a member of the crew in the event of a behaviourally disturbed episode which may compromise the safety of the crew or the mission.
- a privatised compartment capability allowing privacy for crew members communicating with the CPST, family, the crew physician, or taking part in CPSS research platform experiments.

1.4.6.3 Software

Software consists of the policies, procedures and protocols necessary to carry out all CPSS functions. This is the “invisible” managerial infrastructure necessary to integrate the different components of the CPSS system (liveware

and hardware) into a working system capable of fulfilling the requirements designated to the CPSS for maintaining crew health and performance.

1.4.6.4 Research Platform

The CPSS Research Platform provides the capability of supporting in-flight experimentation capable of assessing the psychological, psychiatric, psychosocial, psychophysiological, and cognitive effects of long-duration spaceflight on crews. The platform consists of a laptop computer system capable of administering the experimental test, storing the accumulated data, and transmitting it to the CPST on the ground. Data from the research platform will be used for:

- enhancing the understanding of human performance and behaviour in isolated, confined, and extreme environments;
- developing a database of experimental and observational findings (while protecting the identity of the crew member providing the data) to which the scientific and research communities of the world may have access;
- developing more effective selection, training and psychological countermeasure procedures and criteria;
- monitoring crew psychological health and well-being as well as identifying significant changes possibly indicating poor adaptation, physical or psychological illness, or the inability to cope effectively with the rigors of spaceflight.

Obtained performance data will be transmitted to the Crew Psychological Support Team for collection, documentation, analysis, and categorisation. Performance data obtained from the crew will *not* be used for evaluation purposes. The Research Platform will play a vital role in identifying, understanding, and predicting human behaviour and performance for all future manned spaceflight endeavours.

1.4.6.5 Psychological Countermeasures Training

Given the prominence and consistency with which psychological and psychosocial factors have affected crew performance in spaceflight and space-analogue environments, the Crew Psychological Support System for the Earth orbital facility and Mars base DOCC's must include provisions for training crews to cope effectively with such factors. As stated by Manzey et al., [43] in contrast to short-duration spaceflights (e.g. Shuttle missions) where astronauts' tasks and crew life are highly structured and directed by tight working schedules, procedure lists, and close ground-based control, extending manned spaceflights up to several weeks or even months will considerably increase the importance of psychological issues which might arise in the course of such prolonged missions [44, 45].

The CPSS psychological training regime will begin early in the pre-mission preparation phase immediately following crew selection. Psychological and

psychosocial stressors have been observed not only in the actual in-flight phase of the mission, but in the pre-flight and post-flight phases as well [46]. Psychological countermeasures suggested by Manzey et al. [43] for extended duration spaceflight will be used and are described below.

A) Social Competence Training

Given the significant demands on crew members regarding team co-ordination and performance [44, 47, 48, 49], training in communication and interpersonal skills will facilitate the skills needed for successful crew co-ordination. Specifically, two aspects should be addressed: (1) general knowledge about important aspects of human communication and (2) improving interpersonal attitudes and skills.

1. *General Knowledge of Human Communication*

Training will be given to crew members concerning the fundamental aspects of human communication including how communication is facilitated, why communication takes place (i.e. to exchange information, intentions), the most appropriate time to communicate, potential barriers of communication, and techniques which can be applied toward avoiding misunderstandings and facilitating mutual understanding, and hence successful team performance. In addition, crew members will be trained to develop an understanding and awareness of factors that effect crew communication (i.e. ambient noise produced by spacecraft systems, communication between crew members of different native languages) and how these factors reduce the reliability of the spoken means of communication [50]. Effective communication patterns between crew members have been demonstrated in the aviation field to improve team performance by lowering error rates [51, 52].

2. *Interpersonal Issues*

Training crews in interpersonal issues involves increasing social sensibility and tolerance. Social sensibility aims to develop empathy and improved perception and understanding of feelings, motives, and tensions of other team members. The empirical effectiveness of a similar social sensitivity training program was demonstrated in a simulated space mission experiment in which the training was shown to facilitate more successful team performance [100].

Training in the development of tolerance requires development of readiness to accept the attitudes, values and opinions of others. Also presented by Manzey et al. is the suggestion to train crew members to develop self-awareness which includes (1) realisation of one's own strengths and weaknesses, and (2) awareness of one's own responsibilities for the social atmosphere within the working teams as well as interpersonal relations. Training also includes development in the following areas: (1) feedback skills, such as knowing when to give feedback, developing an appropriate content of the feedback, and learning how to receive feedback constructively, (2) active listening

skills: developing the willingness of crew members to see a problem from the other's point of view and to try to understand the arguments of others instead of arguing with the goal of winning the argument.

B) Stress Countermeasures

The spaceflight environment is rife with psychological stressors which only accentuate with missions of longer duration [36]. Training in stress countermeasure techniques for pre-flight, in-flight, and post-flight stressors is therefore necessary to facilitate crew health and performance.

Recognising that physiological and emotional responses to stressors differ among individuals [53] as well as what is perceived to be a stressor, stress countermeasures for crew will consist of: (1) identification and analysis of situations and conditions considered stressful for each member of the crew, (2) identification and recognition of the individual crew member's stress symptoms, and (3) training in state-of-the-art stress coping techniques.

As perception of stressors and the symptoms experienced during the stress response differ, so do responses to different stress countermeasures [43]. Accordingly, crew members will be trained in a variety of stress countermeasure techniques until one or a combination of techniques are found which best support their needs.

The CPSS training protocol will also include *crew-oriented countermeasures*. Individual-oriented countermeasures, like those previously discussed, represent a necessary but insufficient means to prevent the occurrence of psychological problems including interpersonal tension and other psychological disturbances among crew members [43]. Spaceflight crew members for the long-duration Mars mission will undergo significant training as a united team before the mission to allow them to co-ordinate their tasks, work, personalities, and duties.

1.4.7 Habitability

Habitability factors include sleep, clothing, personal hygiene, habitat aesthetics, recreation, privacy, outside communications, personal space, lighting, noise, and behavioural requirements, and play a vital role in crew health. The importance of addressing habitability issues in the spaceflight environment has become apparent through the experience of Russian space crews, as well as Skylab crews [36].

Lack of proper inclusion of habitability issues in extended-duration human spaceflight creates an inconsistent mismatch between a crew member's attributes and the environmental attributes, thus resulting in strain and eventually, physical and psychological illness [40]. For these extended missions, one can no longer tolerate minimally acceptable living standards nor make do with limited attention to such issues as health maintenance, recreation, and privacy [27].

Habitability issues and their relevance for maintaining crew health and performance are addressed in Section 1.5.

1.4.8 Conclusion

The ability for human crews to successfully operate in a permanently orbiting spacefacility and Mars base environment depends significantly on our ability to adapt crews to the significant psychological, psychosocial, and human-technology and environmental interface stressors characterising these environments. The CPSS will meet this objective by supporting all aspects of crew psychological health and performance through proper crew selection, training, and support.

1.5 HABITABILITY CONDITIONS

Habitability refers to the “liveability” of an environment. It refers to the ability for an environment to provide comfortable physical and psychological attributes. Habitability involves:

- making human activity more effective and improving its results;
- reducing negative influences on human health that could occur in the form of serious physical diseases;
- providing crews with a sense of psychological comfort and aiding in major psychological disturbances.

Consideration of habitability issues increase system effectiveness as a whole and decrease the probability of crew accidents. Habitability issues that must be considered for improving the level of the human’s adaptation to the spaceflight environment include:

- sleep
- clothing
- personal hygiene
- food preparation
- habitat aesthetics
- outside communications
- recreational opportunities
- privacy, personal space
- behavioural requirements in microgravity environment
- temperature
- lighting
- noise

1.5.1 Sleep

Quality sleep is one of the most important factors influencing crew psychological health and productivity. It is common knowledge that sleep irregularity leads to human errors and decreased efficiency. A specific characterisation of the spaceflight environment affecting crew sleep conditions arises due to the rapid alternation of daylight and darkness in orbit, which leads to a desynchronisation in the crew member's sleep cycle.

Desynchronisation can influence crew performance and overall productivity. Measures that can be taken to lessen the negative effects of desynchronisation are:

- Maintaining regular sleep schedules for crews;
- Providing a sleep program (regularity of schedule and autogenic routines to follow in order to hasten the onset and quality of sleep);
- Dimming or altering interior lighting automatically to correspond to night-time at mission control (8-12 hours);
- Insulating sleep chambers;
- Shielding sleep chambers from sound and lighting using doors or insulating covers;
- Locating toilet and hygiene facilities away from sleep chambers to reduce the noise;
- Avoiding or minimising shift work (because of disturbance of sleep due to changing of shifts);
- Avoiding rotational use of sleep chambers (because of the psychological aspects of private space and hygiene issues);
- Including an alarm/communication system in sleep chambers to provide safety in emergency conditions;
- Locating sleep chambers near exits or radiation storm cellar

1.5.2 Clothing

The psychological value of clothing is a major factor concerning productivity. It is a common occurrence for those who find themselves in isolated and confined environments to allow their psychological standards of appearance to decline. Proper hygiene involves changing outer garments weekly, undergarments daily and using different clothing for physical exercises. The subjective feeling of the crew is affected by the appearance of each member of the group, thus it is necessary to establish a schedule of regular clothing changes which will facilitate positive individual and group perception, and decrease the level of social conflicts. An additional means of reducing the psychological stressors involved with clothing is to provide variability in the crew clothing.

Lint reduction can be provided by using shorter pants (less material to generate lint), as well as pre-washing clothes. Locating an exhaust fan/filter near the primary clothing and towel dispensary will reduce lint as well.

1.5.3 Personal Hygiene

Hygiene requirements concern the maintenance of body and clothing cleanliness. Hygiene parameters for long-duration flight have specific features. “Camping out” conditions decrease human performance in long-duration flight. It is necessary to keep in mind that reduced hygiene lowers overall spacecraft habitability. From both the psychological and medical points of view, the problem of addressing personal hygiene issues is of vital importance. For supporting optimum hygienic conditions, several points should be followed:

- Providing personal hygiene facilities for dental and oral hygiene, hand and face washing, body bathing, hair cleaning, hair and nail trimming, shaving and clothing disposal or laundering;
- Providing facilities for daily sponge baths (especially after physical exercise);
- Providing facilities to allow at least weekly full-body showering (twice weekly showers would be better);
- Developing individual hygiene schedules to meet varying hygienic needs;
- Providing at least one full-length mirror to reinforce concepts of self-image.

1.5.4 Food Preparation

Conditions of isolation and confinement are characterised by a lack of access to friends, family, and normal leisure pursuits. In the spacecraft environment, food aspects become one of the most important means for providing psychological health. Two psychological effects regarding food consumption and eating patterns in spaceflight are:

- increased eating;
- increased complaining about the availability and non-palatability of the food.

To compensate for such factors, the following food preparation and eating protocols can be defined:

- Providing self-selection (according to individual weight, calories, and quality of the food);
- Providing a variety of dietary alternatives;

- Providing minimum preparation time;
- Allowing flexibility of preparation (one crew member prepares for all, or each prepares for their own, thus reducing the level of social conflicts);
- Encourage special dinners and celebrations to maintain communication between crew members and to mark the passage of time;
- Encourage crew members to eat together by providing adequate space and regular schedules of meals to facilitate group stability.

1.5.5 Habitat Aesthetics

Scientific data supports the notion that the aesthetics of an environment affect human psychological well-being and productivity within that environment. In order to avoid stress or negative feelings concerning the habitat, it should be designed to be both functional and aesthetically pleasing. It is necessary to deal with the interaction of individual and group preferences by means of:

- Designing private space to accommodate personalisation of decor;
- Discouraging personal decor in common areas.

It is important to provide variation of visual stimuli through colour to influence crew mood, as well as provide increased visual stimulation which is known to decrease in the spaceflight environment.

1.5.6 Outside Communications

Private communication possesses positive and negative sides. Receiving negative information from home leads to serious stress and feelings of guilt. It is a question of individual personality on whether or not to inform the crew member of negative events. Individuals can become completely dependent on communication. Communication use can be defined as a measure of adjustment among isolated groups. As isolated groups are both living and working together, adjustment defines performance. Communications should provide:

- limited amounts of personal audio-channel transmissions, ensuring privacy of personal communication;
- opportunities for each crew member to speak privately to the Crew Psychological Support Team.

1.5.7 Recreational Opportunities

Some recommendations can be made regarding onboard possibilities of leisure:

- Allow books and musical instruments on board;
- Provide space for both personal and common storage of personal belongings;
- Provide on board storage of literature in digital form to supplement hard copy library materials;
- Provide personal, compact tape players with lightweight earphones for leisure, exercise, and selected work-time music appreciation;
- Provide on board capacity for tape player battery recharging;
- Provide capability for on board videotape viewing (an individual or group activity);
- Provide capacity for storage of videotapes (with a wide variety of materials);
- Schedule at least one hour of uninterrupted leisure time prior to each sleep period;
- Encourage conversation among crew by designing areas and equipment (e.g. tables, workstations) conducive to communication;
- Provide constructive leisure opportunities such as formal courses of study;
- Include botanical experiments in station operations as early as possible to incorporate leisure "gardening" with task-related activities;
- Encourage the development of zero-gravity physical games;
- Design ergometer to render exercise more recreational (e.g. with CRT);
- Allow special dinners and their preparation to provide recreation as well as nourishment;
- Design the space station to include as many windows as possible (to reduce feelings of isolation and to provide opportunities to exercise distant vision);
- Allow leisure-time viewing of station exterior and surroundings via system of exterior-mounted video cameras.

1.5.8 Privacy and Personal Space

For issues of individual space the design should include a "library" compartment aboard the space station to allow crew members periodic opportunities for privacy and quiet reflection, and also have individual "privatised" sleep chambers incorporating approximately eighty-four cubic feet of space if library and other common areas are provided. If common areas are not provided, sleep chamber volume requirements increases substantially.

1.5.9 Behavioural Requirements Associated with a Microgravity Environment

The space station interior architecture should be designed to incorporate familiar (Earthlike) features (e.g. room-like chambers), maintaining, to the extent possible, a consistent interior orientation (e.g. local vertical). It should also provide visual and perhaps tactile cues to reinforce a reference frame, developing devices to restrain small objects during maintenance and repair operations as well as developing solutions to problems associated with the stowage of small objects.

1.5.10 Temperature

Temperature is one of the parameters that influences human well-being and performance. Findings show that:

- Decrements in cognition and psychomotor performance take place when temperatures are at or above 30° C. Cognitive tasks are more affected than motor performance tasks;
- Uncomfortably high temperatures can temper outbursts and negative reactions to others;
- Decreases in temperature can produce efficiency decrements and these declines can be found in visual reaction time.

The recommended temperature for space crews is between 18 and 25°C.

1.5.11 Lighting

In the spaceflight environment, lighting becomes an especially important habitability consideration. Proper lighting is important to safeguard vision, minimise annoyance, and to enhance the visual environment. For the defined environment, it will be necessary to maintain levels of illumination adequate for the tasks required, while readapting to lower levels of illumination for general purposes.

1.5.12 Noise

Noise can cause pain and damage to the inner ear, resulting in hearing loss. Even low levels of noise can interfere with communications. Noise can cause physiological stressors (i.e., cardiovascular, autonomic nervous and vestibular systems). One of the impacts of noise is the narrowing of attention (simple tasks can be performed, but more complicated tasks are affected negatively.) The noise levels on spacecraft raise questions concerning the effects of noise on human functioning and well being. For example, it affects perception and performance, adaptation, fatigue and annoyance levels. Unfortunately, noise remains a problem as it is not possible to turn off all machines, equipment and life-support systems which produce it.

1.6 PHYSIOLOGICAL CHANGES DUE TO MICROGRAVITY AND RECOMMENDED COUNTERMEASURES

1.6.1 Introduction

Microgravity influences the physiology of the human body which, because of its terrestrial development, has adopted potent physiological mechanisms that facilitate man's upright posture in a gravity environment. Depending on the time spent on space station or a transit vehicle, microgravity induces changes to various organs and regulatory mechanisms of humans. The human body has a remarkable ability to adapt to this unique environment, allowing near-normal function in microgravity. Several of these adaptations pose potential problems when the crew members return to Earth or other planetary surfaces i.e. to a gravity environment.

Recent experience has shown that various forms of countermeasures are necessary to keep crew members healthy, efficient and fit for work to perform daily tasks. It is necessary for crew members to have sufficient reserve and functional capacity left to survive under emergency conditions, as well for them to be prepared for a safe return to terrestrial conditions or to a successful planetary exploration mission.

1.6.2 Cardiovascular Deconditioning

Neural and hydrostatic responses to the reduction or absence of gravity can affect the cardiovascular system in a very significant manner. Short and long duration spaceflights have been known to cause at least three clinical symptoms indicating that the cardiovascular system is an organ system primarily effected by microgravity exposure.

1.6.2.1 Orthostatic Hypotension

Even though the earliest flights consisted of only a few hours, *orthostatic hypotension* was evident immediately post-flight. This phenomena has persisted and worsened as missions have increased in flight duration. Several different mechanisms have been suggested for the post-flight orthostatic hypotension, and the strongest hypotheses are the following:

A) Decreased Plasma Volume

The increase in central circulatory volume due to the cephalic shift, resulting from μg , is interpreted by the body as an overall increment of the circulating volume (hypervolemia) and this activates mechanisms leading to a significant loss of sodium and water [Leach, 1987, Gharib, 1985] with a resulting hemoconcentration early on in flight.

B) Impaired Muscle-Venous Interaction

The pressure in the tissue surrounding the veins in the lower limbs is an important factor used to control the pooling of blood during erect posture, and act as a counterpressure to the hydrostaticly increased

intravenous pressure. It is hypothesised that muscle atrophy due to unloading of postural muscles in the legs in a microgravity environment [Berg, 1996] will probably decrease with this “counterpressure”.

C) Decreased Interstitial Fluid around Leg Veins

The removal of hydrostatic pressure in microgravity will decrease the transvenous and capillary pressure; therefore, movement of fluid from the interstitial to the vascular space in the lower limbs will occur.

D) Increased Venous Capacitance and Compliance

The compliance of venous vessels in the lower part of the body probably increases (as it does during bed-rest [Guell, 1995]) and therefore accommodates increasing volumes of blood in the lower part of the body when assuming an upright posture.

E) Impaired Arterial Vasoconstriction

Preliminary research results [Churchill, 1996] indicate that impairment in the reflex vasoconstriction seems to be the prominent difference between “fainters” and “non-fainters” during stand tests following spaceflight.

F) Impaired Heart Function

It might be expected that some decrease in cardiac mass might take place under hypogravic and hypodynamic conditions since coronary flow and associated myocardial oxygen delivery have decreased 20-25% during head-down bed-rest studies [Katkov, Chestukhin, Kakurin, 1985], and cardiac dimension and mass decrease with deconditioning [Amsterdam, Laslett, 1985, Eshani, Hagberg, Hickson, 1978].

G) Attenuated Arterial Baroreflex Sensitivity

It has been shown that the capacity of the carotid baroreflex to respond to moment-to-moment changes in carotid transmural pressure was reduced by bed-rest [Convertino et al., 1989] and spaceflight [Fritsch et al., 1992]. It is interesting to note that the aortic baroreflex sensitivity has been shown to increase after bed-rest [Crandall et al., 1994].

H) Attenuated Cardiopulmonary Baroreflex Sensitivity

The cardiopulmonary reflex has not been extensively studied in microgravity. If this reflex was attenuated it would most probably have impact on the orthostatic tolerance; however this has, to date, not yet been shown [Convertino et al., 1994].

1.6.2.2 Decrease in Work Capacity

The second clinical symptom of cardiovascular deconditioning is the *decrease in work capacity* in-flight and post-flight. This persistent condition is evident after very short flights and is aggravated by changes in muscle form and performance with increasing flight duration.

Reduction in stroke volume and cardiac output are primarily responsible for the lower maximal oxygen uptake [Hung et al., 1983, Saltin et al., 1968]. In

addition to the reduction in cardiac size and function, there are also reductions in blood flow [Convertino, 1991] and aerobic pathway enzymes [Hikida et al., 1989]. Furthermore, the 15% loss of red blood cells and 10-25% decrease of haemoglobin is indicative of significant loss of oxygen carrying capacity.

1.6.2.3 Cardiac Rhythm Disorders

The third symptom, which has been observed during Skylab and some Russian longer missions, is *cardiac rhythm disorders*. These have occurred in-flight and during EVA's, but because they have not been a consistent finding or because they have not been induced in ground simulation studies, they may have not received the attention they deserve.

1.6.3 Cardiovascular Deconditioning Countermeasures

Although the reduction in work capacity in-flight appears to be preventable with exercise [Convertino, Sandler, 1995], no effective treatment has been found for post-flight orthostatic hypotension in spite of extensive studies using both flight crews and ground simulation studies. Possible microgravity induced physiological impairments that could give orthostatic intolerance and/or reduced work capability together with procedures that might counteract that impairment are mentioned below.

1.6.3.1 Decreased Plasma Volume

A) In-flight countermeasures:

- Aerobic exercise: fitness is linked to maintaining optimal blood volume [Convertino, Sandler, 1995], at least during Earth conditions.
- Pneumatic cuffs: consists of inflatable cuffs around the thighs which prevent the headward fluid shifts and the concomitant diuresis, these should be used 1-2 h/day [Atkov, 1996].
- Pharmaceuticals: The mineralocorticoids could be an aid to maintain plasma volume during flight. It has been shown that 0.2mg every eight hours of Fludrocortison restored plasma volume during a seven day bed-rest [Vernikos et al, 1991, Vernikos, Ludwig, Convertino, 1992]. It also restored the arterial baroreflex and prevented orthostatic hypotension [Vernikos, Convertino, 1992]. However, occasional adverse effects are seen, [Burns, Brown, Semple, 1983, Chobanian et al., 1979] such as hypertension, hypokalemia or headache, and better knowledge must be obtained before fludrocortisone can be safely used in spaceflight.

B) Upon return to Earth gravity environment:

- Pharmaceuticals: anti-diuretic hormone (ADH) might be an option to restore plasma volume [Nicogossian, 1989].
- Ingestion of isotonic saline or water and salt tablets: ingestion of approximately one litre of isotonic saline two hours prior to re-entry significantly decreases the orthostatic problems after short duration

flights [Bungo, 1985] but does not appear to be as effective as the duration of flight surpasses four to seven days [White et al., 1991]. This is standard procedure on all Shuttle and Mir flights.

- Lower Body Negative Pressure (LBNP, see Section 4.1): the body “senses” decreased blood volume and attempts to restore it, especially if isotonic saline is ingested simultaneously. LBNP is usually also performed in-flight.
- Antigravity suits (G-suits): by applying external pressure to the lower body they prevent pooling of blood in the legs if returning in +Gz attitude during re-entry, and thus maintains central blood volume.

1.6.3.2 Impaired Muscle-Venous Interaction

Strength training of the lower limbs maintains muscle mass, thus maintaining the external venous contact stress to counteract dependent blood pooling.

1.6.3.3 Decreased Interstitial Fluid around Leg Veins

LBNP had beneficial effects in maintaining the extra cellular fluid volume in the lower limbs [Guell, 1995], which contributes to lower limbs external venous constraint.

1.6.3.4 Increased Venous Distensibility

- LBNP and pneumatic cuffs condition the capacitance vessels in the lower limbs and stimulate them towards decreased distensibility. However, this effect of LBNP has not yet been scientifically proved [Guell, 1995].
- Pharmaceuticals: dihydroergotamine or ergotamine alone have been shown to have beneficial effects on orthostatic hypotension [Biaggioni et al., 1990, Hoeldtke, Davis, 1991]. Dihydroergotamine is a peripheral α -adrenergic agonist that causes venous constriction in the legs, and thus acts like an internal G-suit.

1.6.3.5 Impaired Arterial Vasoconstriction

LBNP might act as an “exercise tool” for the vasoconstrictor branch of the baroreflexes.

1.6.3.6 Impaired Heart Function

Aerobic exercise of low to moderate intensity and long duration, has been shown to counteract deconditioning of the heart [Convertino, Vernikos, 1995].

1.6.3.7 Attenuated Arterial Baroreflex Sensitivity

- An exercise protocol designed to elicit maximal aerobic work can acutely correct decreases in baroreflex sensitivity following bed-rest [Convertino, Vernikos, 1995] and could have the same beneficial effects following spaceflight.
- LBNP might also have an exercise effect on the arterial baroreflex.

1.6.3.8 Attenuated Cardiopulmonary Baroreflex Sensitivity

LBNP might also help to condition this reflex.

1.6.3.9 Reduced Work Capacity

- Intensive exercise of 50-75% of maximum capacity for two hours per day during long-term spaceflight has successfully maintained the work capacity for up to a year in Russian cosmonauts [Koslovskaya I B, Grigoriev A, Hamilton D, 1996].
- Maximal exercise sessions every seven to ten days have been suggested to preserve maximal work capacity, endurance time and plasma volume following weightlessness [Convertino, Vernikos, 1995].
- Preserving plasma volume with the before mentioned countermeasures is an important factor to maintaining effective work capacity.
- Pharmaceutical: since erythropoietin levels are decreased in-flight, doses of erythropoietin could restore/maintain red blood cell mass and haemoglobin concentration. Red cell losses are also attenuated by high levels of in-flight exercise [Michel et al., 1977].

All of the previously mentioned disorders are influenced primarily by microgravity environments and, hypothetically, the spacetraveller would benefit to a significant degree if artificial gravity (1g or partial gravity) could be implemented.

1.6.4 Deconditioning of the Skeletal System

The Earth gravity homeostatic forces present during normal activity under terrestrial conditions are absent in the hypogravity environment of space flight. The lack of gravitational loading greatly affects the tropism of weight-bearing bones involved in locomotion and posture maintenance [Schneider, LeBlanc, Huntoon, 1993].

Effects caused by the absence of weight bearing on the bones include:

- Removal of the direct compressive force on the long bones and spine.
- Removal of the indirect loading on the bones from the pull of muscles on the various bone structures to which they are attached [Güell, Tallarida, Wegemann, 1993, Van Loon, Veldhuijzen, Burger, 1996].

In addition to reduced mechanical loading, weightlessness causes other physiological changes, such as fluid shifts and altered hormonal status, which may have additional, independent effects on bone [LeBlanc, Schneider, 1992].

Disuse osteoporosis in microgravity is associated with increased phosphorus and calcium losses and hydroxyproline and nitrogen losses [Johnston, Dietlein 1977, Grigoriev, 1991, Oganov, et al., 1991].

Loss of bone mineral during space flight has been confirmed during early Russian and U.S. experiments and in rats appears to be caused by impaired osteogenesis in the presence of normal [Cann, 1990] or even increased osteoclastic mineral resorption [Veldhuijzen, van Loon, 1994].

Collaborative research between the United States and Russia aboard the Mir space station (1992-1995) measured bone mineral density (bone mass and bone mineral content) in multiple skeletal sites after long-term space missions using transmission densitometry. The greatest losses of mineral density in using this methodology were found at :

Pelvis	(11.99 ± 1.72 %)
Lumbar vertebrae	(5.63 ± 0.82 %)
Proximal part of the femur.	(8.17 ± 1.74 %)

Bone density and mineral content changes of the upper skeleton were absent or slightly increased [Koszlovskaya, 1996].

Unlike other physiologic adaptations, loss in bone mass occurring in the weight bearing bones during microgravity did not reach a steady state during the eighty-four day Skylab mission [Diamandis, 1992].

In contrast to findings in long-term bed-rest studies, the repair and return of bone mineral density in astronauts has not been confirmed and may provide an obstacle to long-term space flight.

The loss of bone mineral from space flights of long duration might lead to:

- Axial skeletal fractures upon re-entry to Earth's gravity.
- Making the space traveller more susceptible to osteoporotic fractures in old age.
- In a microgravity environment the bone fracture healing process is markedly reduced.
- The astronaut seems to be at an increased risk for kidney stone formation because of the increased urinary calcium phosphate, calcium oxalate and uric acid [Schneider, LeBlanc, Huntoon, 1993].

1.6.5 Skeletal System Countermeasures

Existing results from previous American and Russian space missions show rates of bone loss comparable to bed-rest studies without countermeasures, suggesting that the extensive exercise conducted during spaceflight has not been completely effective so far [LeBlanc, Schneider, 1992].

There appears to be a significant body of evidence that supports the ability of exercise to improve calcium retention. Steeger and co-workers demonstrated that physical exercise has a significant positive influence on bone mineral density [Steeger, Rompe, Reichel, 1993].

Two types of skeletal countermeasures that might be implemented during space flight are:

1. Skeletal loading produced by exercise, axial compression, LBNP, impact loading and centrifugation.
2. Administration of several supplement minerals, hormones, steroids, diphosphonates and similar medications [Güell, Tallarida, Wegemann, 1993].

The use of skeletal compression suits and a variety of exercise devices have been used during spaceflight. The emphasis on exercise as a countermeasure has generally been directed upon the cardiovascular system. Resistance exercise using various devices and methods have been used to a lesser extent during crew "free time periods". It is difficult to establish the efficacy of these devices because of the variability in use and non standard regimens [Convertino, Sandler, 1995].

The inability of endurance exercise to maintain bone mineral density during spaceflight is not surprising because resistance training with maximal load or loads over a specific threshold and a specific strain rate (number of sets and repetitions) are the important variables controlling osteogenesis [Cavanagh, Davis, Miller, 1992, Dudley, et al., 1991].

Present knowledge and experience concludes that future design of counteracting devices for skeletal changes must ensure that weight bearing bones are adequately stressed. It seems probable that a combination of exercise and pharmaceutical agents will be necessary during long duration space missions. [LeBlanc, Schneider, 1992, Schneider, LeBlanc, Huntoon, 1993]

1.6.6 Deconditioning of the Muscular System

The muscular system is believed to be directly affected by the lack of gravitational loading. Because astronauts float within the orbiting spacecraft, their leg, back and neck muscles are freed of the load-bearing stresses experienced on Earth. Seen from a muscle physiology perspective, microgravity results in almost complete unloading of those groups of muscles which are responsible for upright posture. Although deterioration of

musculoskeletal function may not present an immediate health or operational hazard during short-term flights, these effects will decrease physical performance in situations that call for muscular strength or power, such as EVA, or in emergency conditions during long duration flight [Berg, Tesch, 1994].

The comparison of pre- and post-flight status with regard to the parameters of muscle physiology showed:

- muscular hypotony; [Grigoriev, 1991]
- muscular atrophy; [Jaweed, 1994, Musacchia, et al., 1992]
- a transformation of Type I into Type II muscle fibres in the predominantly slow twitch anti-gravity muscles; [Baldwin, 1994]
- various ultrastructural abnormalities (disorganised myofibrils, cellular oedema, irregular Z-bodies and fibre necrosis abnormal mitochondria) [Hikida, et al., 1989];
- significant and rapid decrease of strength, greater in the lower than upper limbs and furthermore in extensor muscle groups (posture) more significant than their flexor counterpart [Koszlowskaya, et al., 1990];
- a shift of electromyography firing patterns from low to high frequencies and changes in EMG/force ratio [Convertino, Sandler, 1995].

In-flight investigations during different long-term space missions showed a significant decrease in muscle strength (20-40%) during the first days of flight when compared to pre-flight levels, and demonstrated that the magnitude of muscle deterioration during the following long duration of mission was highly dependent on the level of physical exercise aboard Mir space station [Bachl, et al., 1993 and 1996, Tschann et al., 1994].

1.6.7 Muscular System Countermeasures

Exposure to a microgravity environment leads to:

- Hypokinesia, which refers to a reduced level of contractile activity.
- Hypodynamia, which is a reduction in mechanical loading [Musacchia, Steffen, Fell, 1988].

Although muscle atrophy has been significantly reduced due to intensive countermeasures, it is generally accepted that muscle strength and mass in crewmembers still decreases during space flight [Convertino, 1990].

If maintenance of muscle structure, size and function is perceived as operationally necessary, the use of more resistance exercise must be given greater consideration as part of the development of future exercise countermeasure programs for spaceflight.

The inability of exercise presently used during space-flight to completely maintain muscle strength and mass may reflect the absence of eccentric actions (meaning that the muscle is lengthened and the net muscle moment is in the opposite direction to changes in joint angle) in performance adaptations to resistance training [Dudley et al., 1991].

In contrast to microgravity environments, eccentric muscle actions on Earth are a regular part of our daily ambulatory activities and appear critical to the maintenance of muscle size and function, since greater force development can be achieved compared with concentric actions. It has been shown that the incorporation of eccentric muscle actions, in addition to concentric resistance exercise training represents a more effective and efficient muscle training by producing greater force development during exercise and greater strength gain after training with minimal additional expended energy cost [Tesch, et al., 1990].

In addition to exercise alone some degree of gravity loading may be required to provide effective countermeasures.

1.6.8 Neurosensory and Sensory Motor Functions Deconditioning

Humans depend on interaction of almost every sensory system in the body for spatial orientation. The perceptions of location and position are a result of the brain's ability to integrate visual and auditory signals with vestibular input from gravity- and motion detecting organs in the inner ear and proprioceptive information from different motion, pressure, and temperature sensors. [Clement, Berthoz, 1994, Roll, et al., 1994].

Exposure to microgravity rearranges the relationships among signals from the vestibular, visual, skin, joint and muscle receptors until some level of adaptation to the novel sensory conditions encountered is achieved. Astronauts and cosmonauts often experience the following:

- illusory self and / or surround motions
- space motion sickness
- gaze impairment
- equilibrium control disturbance [Clement, Reschke, 1996]

How the changes in vestibular, proprioceptive and visual systems during development in microgravity affect the postural behaviour of individuals needs still to be investigated. However, locomotion inside a spacecraft is quickly learned.

Based on data from Russian and U.S. flights an amount of about 67% of space travellers will experience symptoms of Space Motion Sickness (SMS) [Clement, Reschke, 1996]. SMS is a very distressing acute condition characterised by a combination of symptoms involving the autonomic nervous system (nausea, dizziness, somnolence, headache, depression and reduced

performance), associated with perceptual oculomotor and postural phenomena [Güell, Tallarida, Wegemann, 1993].

The basic mechanisms responsible for the development of space motion sickness are assumed to be an intersensory mismatch provided either by conflicting afferent information from otolith and semicircular canals from labyrinthine and visual cues. A fluid shift theory dealing with the development of motion sickness has also been proposed.

1.6.9 Neurosensory Countermeasures

Beside preselection/screening there are currently several ways of treating neurosensory deconditions especially space motion sickness but a reliable and validated predictor has not been established.

- A) Pharmacological treatment: Use of anti-motion sickness drugs, for example promethazine hydrochloride (antihistamine), hyoscine hydrobromide (scopolamine), cinnarizine (antihistamine and calcium antagonist properties) and dextroamphetamine sulphate (amphetamine), are effective in reducing or even preventing symptoms, but they generally exhibit undesirable side effects. For that reason, they are not suitable for situations in which the individual is required to perform skilled tasks [Dobie, May, 1994, Vernikos, 1995].
- B) Use of nonpharmacological therapy like biofeedback training, autogenic feedback training and cognitive behavioural therapy have been shown to decrease symptoms of space motion sickness. The disadvantage of these techniques is that they are relatively time-consuming but these techniques do not carry a penalty in terms of side effects [Dobie, May, 1994].
- C) Pre-flight adaptation training (vestibular training) has also been proposed as a means to reduce the detrimental effects of microgravity on the sensory system. The aim is to expose astronauts to various motions and patterns to increase an individuals level of adaptation to vestibular Coriolis acceleration without producing uncomfortable motion sickness through the employment of devices like a rotating/tilting chair, or a tilt-translation device [Dobie, May, 1994].

1.6.10 Immune System Changes

The immune system is a complex system that has a high level of integration and dependency with almost all of the other physiological systems. In addition, it is significantly influenced by different psychological states. This section will very briefly highlight the factors that influence the immune system during spaceflight and suggest countermeasures that aim to strengthen the immunological system. Factors that have influence on the immune response include:

- Age
- Nutrition
- Drug treatment
- Disease states
- Alterations in other physiological systems
- Exercise/hypokinesia (bed-rest)
- Psychological factors
- Radiation (UV, gamma, proton,..)
- Exposure to pathogens

At least the last four factors have a negative influence on the immunological system during spaceflight. That the immune system actually becomes weaker after confinement, bed-rest and spaceflight has been shown in several studies [Schmitt, 1996].

1.6.11 Immune System Changes Countermeasures

The potential countermeasures for immune suppression during long-duration spaceflight (Table 1.6) would aim to diminish the factors that alter the immune response.

Origin	Countermeasure
Chronic radiation (low doses)	Shielding
Acute radiation (high doses)	Shielding Cytokine Treatment (Colony Stimulating Factor) Bone Marrow Transplant
Hypokinesia/microgravity	Physical exercise
Endocrine changes (bone metabolism)	Hormone treatment
Behavioural/Psychological	Selection/training Psychological support Drug treatment

Table 1.6 Suggested Countermeasures Coupled with the Origin of Disturbance of the Immune System

However, a deeper and more complete understanding of the characteristics and consequences of the deterioration of the immune system must be achieved. Areas for future experiment areas could be:

- Hormone changes (neuropeptides)
- Cytotoxic cell activity
- Virus reactivation
- Delayed type hypersensitivity
- Vaccination response
- Psychological evaluations

1.6.12 Exercise Prescription

Exercise has been increasingly used as a restorative countermeasure during spaceflights of varying duration. But there still remains the question: what type, intensity and duration of exercise is required to maintain astronaut

performance and well-being before and during flight, upon landing and during the post-flight period on the Earth or a planetary surface?

The Russian Cosmonaut's Exercise Countermeasure Program:

- The well-developed cosmonaut's exercise countermeasure program employs a four day cycle in which the prescribed exercise is performed for three days with the fourth day optional.
- There is usually a morning and an evening exercise session, each lasting an average of about one hour, in which different aspects of physical conditioning are emphasised.
- In addition, the cosmonauts use an elastic Penguin suit which provides passive stress on antigravity muscle groups during motions.
- Duration, frequency and intensity of physical countermeasures usually increase in the second half of the flight.
- It is now a regular practice on long-term Russian missions to schedule little to no physical countermeasures during the first week of flight, accepting the presence and potential limitations from space motion sickness [Charitonov 1994, Sandler, 1995].

1.7 PHARMACEUTICAL REQUIREMENTS

Pharmacological treatment has been and will continue to be used for a wide variety of disorders during space flight. As the duration of space flight increases, the need for treatment with medications is expected to increase accordingly.

The drug response in the human body, and therefore also the drug's active substance and dosage, depends upon the processes that characterise that drug's absorption, distribution, metabolism, and elimination in the body.

As microgravity affects the human physiology, the function of the gastrointestinal tract, liver, kidney, or the blood flow to them may also be altered. Hence, this will influence the absorption, metabolism, or excretion of the drug. This will in turn influence the contents of the medication kit. However, no extensive study on this subject has yet been undertaken.

For long duration manned space flight missions a pharmaceutical kit shall be part of the medical facility and will have the following requirements:

1. The pharmaceutical kit shall provide the crew with the necessary drugs to optimise work capacity and to prevent and cure medical symptoms [Nicoossian,1994].
2. The pharmaceutical kit shall consist of :
 - medications kit;
 - bandages kit;

- fridge kit for drugs and supplies that need to be stored refrigerated.
- 3. The bandages kit shall provide the necessary supplies to aid the crew in case of:
 - fracture and dislocation
 - head and neck injury
 - lacerations
- 4. The quantity of drugs and bandages shall depend upon:
 - crew size
 - duration of the flight
 - probability of occurrence
 - drug absorption and elimination in partial- and microgravity

1.8 DENTAL KIT

For long duration manned space missions a regular (every two weeks) dental check-up is necessary in order to avoid major dental problems. Therefore, a dental kit should be part of the medical facility.

The dental kit shall supply the crew with the necessary equipment for the regular dental check-up and shall also provide the tools and material to treat toothache.

The dental kit shall consist of two separate parts. One shall contain the equipment and the other shall contain the consumables. Only the latter part will vary for different scenarios.

1.9 SURGICAL REQUIREMENTS

With the increased number of manned space missions, the building of the International Space Station, and the planning of a manned Mars mission, trauma and surgical problems are beginning to gain more and more importance. This is the reason to address these problems in their own section, making a clear separation from other medical problems. Also, anaesthesia and intensive care medicine will be addressed.

1.9.1 Surgical Problems Classification

This section provides a classification for trauma and surgical problems, describing the specific conditions, their treatment and the hardware needed.

1.9.1.1 Minor

- *Conditions:* lacerations, contusions, abrasions, first degree burns, abscess (peri-rectal or paronychia), haemorrhoid thrombosis, foreign body in the eye, nasal haemorrhage.

- *Treatment*: cleaning, disinfecting, suture and bandage of lacerations, contusions, abrasions and burns under local anaesthesia; drainage of abscess or haemorrhoid's thrombus under regional or intra-venous anaesthesia; removal of eye foreign body with local anaesthesia; tamponing of nasal haemorrhage.
- *Hardware*: surgical box nr. 1 (ten surgical instruments), drugs (local, regional and intravenous anaesthetics; disinfectants - iodine povidone, alcohol; antibiotics), bandages, aseptic towels, drapes and gloves, masks and hats, needles, syringes and IV systems.

1.9.1.2 Moderate

- *Conditions*: appendicitis, fracture, glottis oedema or larynx impacting with a foreign body, fractures of small bones of hand and foot.
- *Treatment*: surgical operation under general anaesthesia, fracture immobilisation, cryothomy under local anaesthesia (create an airway).
- *Hardware*: open surgery equipment (surgical box nr. 2 with 25 surgical instruments), laparoscopic surgery equipment (optic scope, light cable, light source, CO₂ inflator with tubes, TV camera, monitor, 6 endoscopic surgical instruments, irrigation/aspiration device with tubes), anaesthesia equipment (ventilator; laryngoscope; traqueal tube), nasogastric tube, drains, sutures, staplers, plaster bandages, fracture restraint devices, sterilisation facility.

1.9.1.3 Major

- *Conditions*: penetrating injuries of visceral cavities, blunt thoracic trauma (with hemo/pneumothorax) and abdominal trauma (with internal haemorrhage), second and third degree burns, skull fractures (including subdural and epidural hemathoma following severe head trauma), spinal trauma, instability of major joints.
- *Treatment*: major surgical operation (could last for two hours) and thoracic drainage under local anaesthesia using a subaquatic closed system.
- *Hardware (same as for moderate plus the following items)*: surgical box nr. 3 with forty surgical instruments, cell saver device (for patient's blood reuse), thoracic tubes and subaquatic systems.

1.9.2 Environment and Surgery

The surgical constraints and countermeasures are the same regardless of the mission/scenario considered, and will be discussed in this section.

1.9.2.1 Microgravity Constraints

When doing surgery in a microgravity environment such as in an orbital station or on a manned mission to Mars, the most important problem is to restrain the blood and all the intra-abdominal organs so that they do not float

around when the abdominal cavity is opened. If there is a haemorrhage in a superficial part of the human body one can control it with pressure, applying a tourniquet upwards of the local of initial haemorrhage, then making a proper suture. But when one opens the abdomen, all the internal organs start floating around, unless countermeasures are used to restrain them.

The first problem is to assure an aseptic environment. Second, a way of keeping the organs in place is needed. Third, the surgical field must be kept clear of blood.

1.9.2.2 Countermeasures

- A) Endoscopic procedures vs. open surgery: In laparoscopic surgery the abdomen is not opened; instead, the virtual intra-peritoneal cavity is inflated with CO₂ gas to create a space to work. The difference when working in a microgravity environment is that the organs, mainly the bowels, will float inside the abdomen instead of staying in a downwards position. When there is a need to hold the internal organs “down” so work can be done, the cavity can be inflated with water or a big semi-rigid mesh can be inserted just for the time needed. With this method appendectomies, gallbladder surgery, and trauma surgery can be performed, as well as many other surgical operations.
- B) Artificial gravity: If it is possible to have some gravity (0.39g as in Mars) for about one or two hours it should be possible to perform an appendectomy or other kind of surgical operation with not as many problems as in microgravity. The challenge to the engineers is to build a centrifuge that could be “pulled out” of the spacecraft just for the necessary time to perform the operation, or just have the spacecraft spinning around for the needed time.
- C) Glovebox: Another possibility to deal with microgravity could be to use a glovebox that could be positioned over the patient and around the locale of trauma or around the abdomen if abdominal surgery must be performed [Markham, 1991]. A sterile environment can exist, and by applying continuous suction/irrigation or laminar flow a clean surgical field will result. There have been some experiments made during parabolic flights by both NASA and Russian medical specialists with such a device that proved to be successful.

1.9.2.3 Anaesthesia

In microgravity environments, care should be taken when using general anaesthesia so those anaesthetic gases that escape do not contaminate the entire spacecraft with the risk of anaesthetising all the crew. In most cases and when it is possible, local, regional or intra-venous anaesthesia should be used. When it is mandatory to use general anaesthesia, a closed circuit system should be specifically designed for recovery of the anaesthetic gases.

1.9.2.4 Intensive Care Medicine

The core module of the DOCC contains a one-bed Intensive Care Unit (ICU) that can adapt itself to receive more patients. All the procedures and protocols used in Earth ICU's can be put together so that a standard protocol can be adopted and used, with the help of the CHMS to make a 24-hour monitoring system.

1.10 COMPUTERISED HEALTH MAINTENANCE SYSTEM

In order to support the Medical Requirements of the DOCC, a Computerised Health Maintenance System (CHMS) must be developed. This system will have the following requirements:

1. Provide an on board computerised medical record system because paper records can be very heavy, cumbersome, and difficult to share with ground facilities.
 - The medical record system should have an electronic connection with medical hardware so that data from various instruments can be easily transferred to the record system.
 - The record system should also have a diagnostic capability to perform limited processing of the data. For example, the record system should be able to analyse EKG's for anomalies, or to take blood analysis results and suggest a differential diagnosis for any abnormalities. The system should also contain preventive and therapeutic algorithms. This capability will become extremely important in emergency situations where expert advice may not be immediately available such as on a Mars mission or in instances where the communication hardware fails.
 - The record system should also be capable of transmitting medical images (e.g. X-rays), monitoring information (e.g. ECG's), and capable of sending/receiving patient data.
2. Provide space vehicle to ground station e-mail, audio, and visual data. Both audio and visual data may need to be transmitted at the same time. Communication will occur in real-time when the system is in close proximity to the ground support system. Two "private" communication lines are essential to maintain patient confidentiality. One private line will be used exclusively for the interactions between medical personnel and ground support systems. The second ground support line will be used as a redundancy for the first ground link and also for communication between the space vehicle crew and the ground system.
3. Provide access to electronic medical literature which may be used to help assist in any medical procedure. Medical personnel will also receive updated and review medical training via the computer system.
4. Provide a computerised medical inventory system for medical supplies, pharmaceuticals, and electrical power. This system will be programmed

with the shelf-life of medical drugs and all changes to the quantity of stock of drugs will be updated automatically. This will allow resupply requests to be sent automatically. In addition, the system will also make suggestions when medical hardware that use large amounts of electrical energy may be used. Bar codes will be used on most medical items and crew members will be required to log all pharmaceuticals which are dispensed.

5. The system will be required to be backed up at regular intervals, especially patient records. The data should be backed up at an area remote from the CHMS. The components of the system should also be modular so that they can be easily repaired.
6. Information interchange between medical components and the CHMS should occur via a common bus. Medical instruments must be designed to communicate with this bus.
7. All graphical output should be capable of being displayed on a single monitor. Data from different medical devices should either be displayed in separate windows on the same monitor or integrated into a common display. A portable wireless monitor should also be available for redundancy and to display data in remote locations of the space craft. This redundant monitor may be attached to a laptop computer.
8. A standard format for computer hardware is needed so that components may be interchangeable in instances where failures occur.
9. Long term tracking of medical data will also be performed by the computer. This will include all lab values, counter measure test results, and psychological test results to monitor long term changes.

1.11 TELEMEDICINE

1.11.1 Introduction

Telemedicine is one of the fastest growing technologies that will help the space physicians using the DOCC. Telemedicine provides access to medical expertise, even if the patient is far from a specialised health care facility as occurs in space environment. Telemedicine can speed up both diagnosis and treatment by "eliminating" the distance between patient and the treatment provider.

Telemedicine can be defined as the use of electronic signals to transfer medical information from one site to another. The technology used to perform telemedicine can range from a simple telephone on Earth, to satellites in a space environment, to a long range communication network from Earth to Mars. Although the definition is broad, telemedicine refers to uses of telecommunications technologies to facilitate health care delivery. The DOCC facility would use telemedicine extensively in the orbital and first part of the Mars travel scenarios. The Mars base would be too far away from Earth for a real time link. Therefore only elective medical links, which can have time delays, would find a good use of this new technology.

Telemedicine applications on the DOCC will range from radiology to psychiatry. There has been some simulation of surgery via telemedicine already in microgravity environment on the parabolic flights and more are needed to define the standard and protocol which should be used on the DOCC.

Telemedicine dates back to the 1920's, when radio was used to assist ships at sea that had medical emergencies. In NASA, another type of ship is used, a space ship. During NASA's Apollo project, telemedicine played a key role for the success of landing a man on the moon. Physiological monitoring was accomplished by transferring the data back to the Earth ground station. Later the ATS-6 satellite projects in the 1970's linked paramedics in remote Alaskan and Canadian villages with large hospitals in large cities that were far away.

1.11.2 Telepresence in Medicine

Telepresence techniques could allow surgeons to conduct robotic surgery from anywhere where facilities exist and this would offer patients an increased accessibility to specialists. Prototypes have been tested that let the surgeon experience all the sensory feedback and motor control that would be experienced in person. Telepresence could also be used to protect medical professionals from potentially harmful environments such as an infection exposure or the extreme environment of space.

Telemedicine enables fixed facilities to become dual-use assets that can be expanded with the use of telepresence. It also enables maximum utilisation of hospital beds by integrating it with other computer systems like the U.S. army tri-service aeromedical evacuation and medical regulating system.

The DOCC Telemedicine system will provide more robust, higher bandwidth medical telecommunications with direct link capability to speciality care physicians anywhere around the globe. The space segment can transmit live video and high resolution medical images to support more detailed diagnosis and treatment processes. The ground segment's computer system will be configured to meet a go-anywhere, do-anything approach to support any situation.

The DOCC Telemedicine system will include: a special platform with a medical imaging workstation, computer displays, satellite and terrestrial communication, capability for full motion medical video and multimedia applications, multi-sensor packages.

Another new technology which will be used on the DOCC will be the Personal Status Monitor (PSM) which is a U.S. Army development device. The PSM will provide the Astronaut's physiologic monitoring data, which can be easily sent to medical centres for physiological monitoring. None of the items are currently ready for real-world use, but will be soon.

Space will play an integral role in the transformation of telemedicine and telepresence. The space agencies have always been a leading-edge developer and user of technology and are currently the sole providers of true space telemedicine. The DOCC is a good example of the use of this new technology

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Chapter 2

Hardware for DOCC

In Chapter 1 all relevant medical events for manned space missions have been discussed. An overview has been given of what is known in terms of crew selection, crew psychological support, habitability conditions, physiological deconditioning and recommended countermeasures, pharmaceutical and surgical requirements, dental events, computerised health maintenance and telemedicine. This has led to functional requirements for the DOCC. These functional requirements can be transformed in hardware requirements.

In this chapter, the results of this next step are presented. The required hardware is very complex, therefore the results are presented in table form (Table 2.1) to make the information available in a very concise way. The hardware table consists of the required component, the function it has to provide and (where possible) with the physical characteristics such as volume, mass and required power.

Much of this table was adapted from the NASA document, "Crew Health Care System (CHeCS) Hardware Specification".

Abbreviations used in this table:

CM:	Crewmember	ECLSS:	Environmental Control & Life Support Systems
CMO:	Crew Medical Officer	IV:	Intravenous
ECG:	Electrocardiograph	SC:	Spacecraft

HARDWARE	PERFORMANCE CHARACTERISTICS	PHYSICAL CHARACTERISTICS
Medical Computer System		
1. Laptop Computer	Computerised Diagnostic System. Medical Reference System (textbook style). Computer assisted inventory management system. Treatment protocol and Medical Database. Transmission of data/ images/ video/ teleconferencing. Medical record of crewmembers.	m= 2 kg V= 1.5 l
2. Video Monitors	colour, high resolution, flat screen. usage: imaging system (X-ray, endoscopy, microscope & camera).	m= 1 kg V= 1.5 l
3. Software		
Portable First Aid		
1. Airway Management System	The Airway Management System shall consist of: Manual Pulmonary Resuscitator (a device to manually ventilate and oxygenate the CM until the CM can be transported and attached to the Ventilator in the Intensive Care Unit or the Ventilator in a Rescue Vehicle); Oral Endotracheal Intubation Tube; Tracheal Tube with stylet for emergency cricothomy.	Items 1-3: m= 12 kg V= 60 l

HARDWARE	PERFORMANCE CHARACTERISTICS	PHYSICAL CHARACTERISTICS
2. Pharmaceuticals & Supplies	Medication and supplies for emergency resuscitation and stabilisation of an injured CM.	
3. Standard Diagnostic Tools	see STANDARD DIAGNOSTIC TOOLS	
4. Defibrillator	The Defibrillator provides a means of defibrillating the heart, correcting abnormal electrical conducting patterns in the heart, and provides continuous visible and audible electrocardiogram (ECG). The Defibrillator shall be portable. The Defibrillator shall produce an audible warning signal prior to discharging electric current, and shall be electrically isolated.	m= 12 kg V= 32 l
5. Crew Medical Restraint System	The CMRS provides a restraint surface and a transport mechanism for an ill or injured crewmember and shall provide cervical spine stabilisation. The CMRS provides a restraint mechanism for two Crew Medical Officers so that both hands are free for operations (example: chest compression during cardio-pulmonary resuscitation [CPR]), rather than for restraint of themselves. The CMRS shall, in addition to a transport role, enable and support the performance of surgical procedures, orthopaedic procedures, monitoring procedures, and dental procedures.	m= 9 kg V= 90 l
Standard diagnostic tools		
1. Blood Pressure Measurement Device	Inflatable elastic cuff to encircle the arm and provide an indication of diastolic and systolic blood pressure (Sphygmomanometer).	

HARDWARE	PERFORMANCE CHARACTERISTICS	PHYSICAL CHARACTERISTICS
2. Ophthalmoscope	Handhold instrument for examination of the eye.	
3. Otoscope	Handhold instrument for examination of the ear.	
4. Digital Stethoscope	Electronic amplification and filtering capability so that CM's heart sounds can be heard despite relatively loud decibel level within SC.	(Standard stethoscope)
Intensive Care Unit Equipment		
1. Blood Pressure Measurement Device	A device that measures the systolic and diastolic blood pressure. The Blood Pressure Measurement Device shall interface with the Electrocardiograph monitor so that blood pressure is digitally displayed.	
2. Defibrillator	The Defibrillator provides a means of defibrillating the heart, correcting abnormal electrical conducting patterns in the heart, and provides continuous visible and audible electrocardiogram (ECG). The Defibrillator shall be portable. The Defibrillator shall produce an audible warning signal prior to discharging electric current, and shall be electrically isolated.	m= 12 kg V= 32 l
3. Electrocardiograph (ECG)	The ECG shall provide a measurement of the quality of electrical conduction in the heart and the integrity of the heart muscle. Automatic measurement of blood pressure (non-invasive - systolic, diastolic, mean) - with cuffs, ECG (12 lead, 3 channel), pulse, respiration, body temperature, gas analysis (CO₂, O₂), electronic stethoscope, Arrhythmia Detection, Alarm.	Mass: 10 kg Volume: 10 l Power: 100 W

HARDWARE	PERFORMANCE CHARACTERISTICS	PHYSICAL CHARACTERISTICS
4. Electroencephalograph (EEG)	Neurological exam (brain waves, brain lesion).	m= 2 kg; V= 1 l
5. Intravenous Pump	The Intravenous Pump shall regulate and control the fluids delivered to the patient.	
6. Pharmaceuticals & Supplies	See PHARMACEUTICAL / SUPPLIES	
7. Metabolic Gas Analyser (MGA)	Measures flow rates and concentrations of inspired (oxygen) and expired (carbon dioxide) gases of an injured crewmember.	Weight TBD Volume TBD
8. Oximeter	Shall provide a measurement of the level of oxygen in the blood.	m= 5 kg ; V= 3 l
9. Temperature Probe	Provides accurate measurement of body temperature of CM. Shall interface with the display monitor of the Electrocardiograph (ECG).	V= 6 cm ³
10. Ultra-sound Device (2-Dimensional Echograph)	Used to visualise the structure and integrity of various internal organs (e.g. heart, abdominal organs), bone density, and to measure the volume of nitrogen bubbles present in the blood and tissues in Decompression Sickness. Doppler capabilities (permits analysis of blood flow rates). Video downlink possible.	Mass: 46 kg Dimension (mm): 433*511*503 Power: 140 W
11. Ventilator	Provides capability to resuscitate and sustain an ill or injured crewmember with impaired pulmonary function.	m= 12 kg V= 45 l
12. X-ray Device	Shall provide a visualisation of bone integrity and the internal state of the body.	m= 2 kg; V= 1.5 l

HARDWARE	PERFORMANCE CHARACTERISTICS	PHYSICAL CHARACTERISTICS
Pharmaceuticals & Supplies		
1. Pharmaceuticals	The pharmaceuticals shall provide treatment for diseases and medical conditions. All pills, capsules, liquids, and glass syringes shall be wrapped so that they are not damaged by launch vibrations.	m= 7 kg V= 3 l
2. Intravenous (IV) Fluids	IV fluids shall restore fluid and electrolyte balance. IV fluids shall be stored in refrigerator.	m= 15 kg V= 15 l
3. Bandages, Gauze, Sterile Drapes	Shall be used to dress wounds and provide a sterile field for surgical procedures.	m=3 kg V= 12 l
4. Plaster, Splints	Shall be used to splint and cast fractured bones.	
5. Blood Supply	Transfusion of critically ill CM. Shelf life of frozen blood is 180 days, therefore autologous donation of blood (CM donates her own blood for storage) every 180 days. Supply shall contain 3 litres of blood per CM (Total volume of blood in the human is 5 litres).	m= 9 kg V= 9 l
6. Refrigerator	Storage perishable medical supplies and blood products.	m= 25 kg V=100 l Temp. Range: 4C/15C
7. Freezer	Storage of perishable medical supplies and blood products.	m= 25 kg; V= 100 l Temp. Range: -190C/0C

HARDWARE	PERFORMANCE CHARACTERISTICS	PHYSICAL CHARACTERISTICS
Surgical Equipment	See Chapter 1.9.1.	
1. Anaesthesia Equipment	The AE shall mix anaesthetic gases in appropriate mixtures for induction of anaesthesia (loss of sensation) and analgesia (relief of pain) required during major and minor surgical procedures.	m= 2 kg V= 1 l
2. Endoscopic Surgery Kit	Equipment used to perform endoscopic operations. (A tube is inserted into various body orifices to visualise the interior of the body. The endoscope has the capability to remove tissue samples by means of remotely operated instruments). Composed of: Endoscope; Light source; TV camera; carbon dioxide inflator.	m= 5 kg V= 4 l
3. Surgical Glove Box	The Surgical Glove Box shall: • be a transparent covering of the surgical field; • remove blood and body fluids from the surgical field by means of laminar air flow; • shall permit the CMO to visualise the surgical field; • shall permit the entry into the surgical field of the CMO's hands and those of an assistant. • shall provide attachments for the head of the Surgical Table.	m= 6 kg l= 65 cm w= 65 cm h= 20 cm
4. Sharp Trash Container	The sharp trash container shall: contain needles, syringes, scalpels, and glass; retain its contents during subsequent openings; be portable and puncture resistant; be marked with a Biohazard label.	V= 1 l (inside a drawer attached to the surgical table)

HARDWARE	PERFORMANCE CHARACTERISTICS	PHYSICAL CHARACTERISTICS
5. Soft Trash Container	The soft trash container shall contain both wet and dry trash, including paper, gauze and bandages possibly containing blood, emptied urine collection bags, excess medications, and other liquids. After a maximum of 24 hours, or when full, the container shall be removed and transferred to Flight Crew Systems for further processing.	V= 1 l (50 bags)
6. Sterilisation Equipment	Kills micro-organisms present on surgical instruments so that the instruments may be re-used. Container that fit instruments inside, with an attached bottle of gas (gas sterilisation).	m= 2 kg (Bottle = 2 l) Dimensions 30*10*10cm
7. Surgical Image Overlay / Heads Up Display	Imaging Device worn on the head of CMO while performing surgery.	
8. Surgical Instruments	See Chapter 1.9 Surgery.	
9. Surgical Table	The Surgical Table shall provide a surface upon which the CM may be restrained for surgery. The Surgical Table shall permit attachment of the Surgical Glove Box and Dental Glove Box and retract into the wall or floor when not in use.	Dimensions: 200cm*65cm (When open)
11. Urine Collection System (UCS)	The UCS shall provide the means of collecting urine from a crewmember whose medical condition precludes the use of the personal hygiene facility. Shall consist of external catheters, and a collection bag assembly, contain a maximum of 3000 ml, and provide visualisation and measurement of urine quantity.	V= 3 l (Shall contain a maximum of 3 l)
12. Body Bag	Container for storage of deceased CM. Must be hermetically sealed and discourage growth of micro-organisms.	m= 2 kg V= 2 l

HARDWARE	PERFORMANCE CHARACTERISTICS	PHYSICAL CHARACTERISTICS
Dental Equipment		
1. Dental Ancillary Supplies	Materials used to perform dental treatments.	
2. Dental Handhold Instruments	Equipment to perform a dental examination.	
3. Restorative Materials	Used to repair fractured tooth and cusp.	
4. Dental Glove Box	The Dental Glove Box shall be a transparent covering of the dental surgical field to be used in the event that a dental drill is used to operate on a tooth. The Dental Glove Box shall remove blood, saliva, and particulate matter from the dental surgical field by means of laminar air flow, permitting the CMO to visualise the surgical field. The Dental Glove Box shall permit the entry into the surgical field of the CMO's hands and those of an assistant. The Dental Glove Box shall provide attachments for the head of the Surgical Table.	m= 2 kg V= 2 l
5. Sterilisation Equipment	Kills micro-organisms present on dental instruments so that the instruments may be re-used. (Same as for Surgical Equipment)	
Clinical Chemistry Analysers		
1. Capnograph	Measures blood carbon dioxide levels, especially in the event of increased spacecraft carbon dioxide level because of ECLSS-Toxicology failure.	

HARDWARE	PERFORMANCE CHARACTERISTICS	PHYSICAL CHARACTERISTICS
2. Complete Blood Count Analyser	Provides measurements of the numbers and type of red and white blood cells within the blood.	
3. Centrifuge	Used to spin tubes containing samples of blood so that certain parameters of blood chemistry can be ascertained.	
4. Optical Microscope and Camera	See ECLSS:Microbiology System.	
5. Occult Blood Strip	A small strip of paper that indicates the presence of occult blood (invisible to the naked eye) in the stool (faeces). The Occult Blood Strip shall be disposed of after use. A roll of strips contains enough strips for a 3 year mission.	
6. Serum Multiple Analyser	Provides measurements of the concentration of various constituents within the blood (example: sodium, potassium, chloride, glucose, calcium) and in the urine. Analyses both blood and urine.	
7. Slide Staining Apparatus	See ECLSS:Microbiology System.	
8. Urine Dipstick	A small strip of paper that indicates the concentration of various constituents in the urine. If any values are suspect, further urine chemistry (urinalysis) can be performed using the Serum Multiple Analyser (see above).	m= 100 g V= 70 cm³

HARDWARE	PERFORMANCE CHARACTERISTICS	PHYSICAL CHARACTERISTICS
Exercise Counter-measures Equipment		
1. Treadmill	Used for systematic aerobic and cardiovascular conditioning through stationary running exercises without disturbing the microgravity environment required. The treadmill shall have a maximum translation of +/- 1 inch in any axis during exercise.	Dimensions: l= 120 cm w= 40 cm
2. Cycle Ergometer	Used for systematic aerobic and cardiovascular conditioning and periodic fitness evaluations without disturbing the microgravity environment. The Cycle Ergometer shall be capable of performing independent upper and lower body limb cycle activity.	Weight TBD Volume TBD
3. Multi-Axial Resistive Exerciser	Used for exercising and testing the major muscle groups in the isometric (muscle length does not change), isotonic (muscle load does not change), and isokinetic (velocity of muscle shortening remains constant) modes. The following resistance exercises can be performed: Shoulders; Forward / Lateral / Backward Raises; Shoulder Shrugs; Chest; Bench Press; Chest Flies; Arms; Triceps Extensions; Biceps Curls; Wrist Curls; Legs; Squats; Heel and Toe raises.	Weight TBD Volume TBD
4. Lower Body Negative Pressure (LBNP)	Shall be capable of inducing fluid shifts to the lower extremities similar to those imposed by a one-g environment. The LBNP shall be used to partially counteract the headward shift of body fluids associated with microgravity.	Weight TBD Volume TBD

HARDWARE	PERFORMANCE CHARACTERISTICS	PHYSICAL CHARACTERISTICS
Exercise Counter-measures Monitoring Equipment		
1. Blood Pressure / Electrocardiograph (BP/ECG)	The BP/ECG shall measure and record the following, during periodic fitness evaluations: systolic blood pressure; diastolic blood pressure; heart rate; heart rhythm. The BP/ECG may also be used in routine medical examinations and in the event of injury to a crewmember.	Weight TBD Volume TBD
2. Metabolic Gas Analyser	Measures flow rates and concentrations of inspired (oxygen) and expired (carbon dioxide) gases during periodic fitness evaluations. The Metabolic Gas Analyser may be used to monitor gas exchange and respiratory function of an injured crewmember.	Weight TBD Volume TBD
3. Bone Densitometer	Provides bone density measurements and bone stiffness measurements.	m= 10 kg P= 60 W Dimensions = 30*35*15(cm)
4. Body Mass Measurement Device	Accurately measures the mass of the human body in a microgravity environment. Calculates mass by analysis of the acceleration response to the application of a given spring pull force.	Weight TBD Volume TBD

HARDWARE	PERFORMANCE CHARACTERISTICS	PHYSICAL CHARACTERISTICS
ECLSS - Microbiology System		
1. Fungal Spore Sampler	Used to monitor the density and type of fungal spores in SC air. Samples collected by the Fungal Spore Sampler shall be processed by using the: Microscope / Camera; and the Microbiology Safety Cabinet.	Weight TBD Volume TBD
2. Incubator	Insulated chamber providing optimal temperatures to support growth of micro-organisms from clinical and environmental sources. The incubator shall be contained within the Microbiology Safety Cabinet.	Weight TBD Volume TBD
3. Microbial Air Sampler	Portable device used to monitor the airborne microbial level in SC. Samples collected in the Microbial Air Sampler will be processed by using the: Incubator; Slide Staining Apparatus; Microbiology Safety Cabinet; Microscope / Camera.	Weight 2 kg Volume TBD
4. Microbiology Safety Cabinet	Provides an enclosed work area for aseptic processing of environmental and clinical samples requiring microbiological analyses. Shall contain the Incubator and Slide Staining Apparatus and provide vertical laminar air flow. Filtered air returned to the cabin shall meet or exceed the quality of input air.	Weight TBD Volume TBD
5. Optical Microscope and Camera	Provides capability for observing, analysing, and photographing stained and unstained preparations of biological samples that have been prepared in the Microbiology Safety Cabinet and Slide Staining Apparatus.	Power: 130 W (28 VDC)

HARDWARE	PERFORMANCE CHARACTERISTICS	PHYSICAL CHARACTERISTICS
	A 35 mm camera shall be affixed to the microscope.	
6. Slide Staining Apparatus (SSA)	An automated, enclosed, leak-proof chamber in which fixed slides are stained for microscopic evaluation. The biological sample is “fixed” with a chemical liquid so that it does not degrade or change in appearance. The Slide Staining Apparatus shall be contained within the Microbiology Safety Cabinet.	Weight TBD Volume TBD
7. Surface Sampler Kit (SSK)	The Surface Sampler Kit shall be used to detect bacteria and fungi that may reside on SC surfaces. The Surface Sampler Kit shall be portable. Samples collected in the Surface Sampler Kit will be processed by using the: Incubator; Slide Staining Apparatus; Safety Cabinet; Microscope / Camera.	Weight TBD Volume TBD
8. Water Microbiology Kit	Detects, enumerates, and selectively identifies the microbial load of SC water. The Water Microbiology Kit shall be portable. The Water Microbiology Kit shall detect 100 Colony Forming Units of aerobic bacteria per 100 ml of water. The Water Microbiology Kit shall detect coliforms (bacteria normally present in human faeces, but medically undesired in drinking water). Samples collected in the Water Microbiology Kit will be processed by using the: Incubator; Slide Staining Apparatus; Microbiology Safety Cabinet; Microscope / Camera; Water Sampler and Archive.	Weight TBD Volume TBD

HARDWARE	PERFORMANCE CHARACTERISTICS	PHYSICAL CHARACTERISTICS
ECLSS - Radiation System		
1. Radiation Dosimeters	Monitor the radiation dose levels inside SC and is composed of: <u>1. Crew Passive Dosimeters (CPDs)</u> • shall measure the absorbed dose to a crewmember and worn all times. • consists of Thermoluminescent Dosimeter chips of lithium fluoride and Plastic Nuclear Track Detectors. • is launched and returned with each crewmember, or exchanged for a new CPD for an extended mission. <u>2. Radiation Area Monitors (RAMs)</u> • deployed at fixed locations on the SC, and replaced quarterly. • shall measure the absorbed dose to designated fixed locations. <u>3. High Rate Dosimeters (HRDs)</u> • is a self-reading pocket ionisation chamber for use during high-dose-rate contingencies that may saturate other active equipment. • will be placed at fixed locations within the SC and replaced quarterly.	m= 1.5 kg V= 1 l Dose level: 600 rads
2. Extra-Vehicular Charged Particle Directional Spectrophotometer	Shall measure the flux of trapped, secondary and galactic cosmic rays as a function of time, charge, energy, and in three directions on a fixed external location of the SC.	m= 32 kg V= 120 l Voltage: 120 V

HARDWARE	PERFORMANCE CHARACTERISTICS	PHYSICAL CHARACTERISTICS
3. Intra-Vehicular Charged Particle Directional Spectrophotometer (IV CPDS)	Shall measure the flux of trapped, secondary and galactic cosmic rays as a function of time, charge, energy, and in three directions inside the SC. The IV CPDS shall be located in a fixed position in each module for 7 days, and then rotated to a new position.	m= 7 kg V= 50 l
4. Tissue Equivalent Proportional Counter (TEPC)	The TEPC is a portable radiation exposure monitor used to monitor the internal radiation dose absorbed by the SC crew. The TEPC shall be located in a fixed position in each module for 7 days, and then rotated to a new position. The TEPC shall operate continuously and display absorbed dose.	Mass: 4 kg Dimension (mm): 230*160*130 Power: 5 W
ECLSS - Toxicology System		
1. Capnograph	Shall provide a measurement of carbon dioxide levels in the blood in the event of increased carbon dioxide level within the SC (See Clinical Chemistry Analysers).	
2. Compound Specific Analyser - Combustion Products (CSA-CP)	The CSA-CP detects and quantifies (parts per million) specific compounds (carbon monoxide, hydrogen chloride, hydrogen cyanide) in the SC atmosphere that arise as a result of a combustion event. Audible and visible alarms warn the crew when contaminant concentrations exceed maximum allowable limits.	m= 7 kg V= 35 l
3. Compound Specific Analyser - Hydrazine (CSA-H)	Used to detect and quantify (parts per billion) the presence of hydrazine propellant in the airlock atmosphere that arise as a result of hydrazine contamination from an EVA crewmember.	m= 6 kg V= 14 l

HARDWARE	PERFORMANCE CHARACTERISTICS	PHYSICAL CHARACTERISTICS
	Will be operated as a portable instrument and will be used primarily in the airlock(s) after an EVA. The CSA-H will have the capability to transfer stored data to an onboard data storage device.	
4. Volatile Organic Analyser (VOA)	The VOA detects and quantifies (mg/m^3) a minimum of 30 targeted individual organic contaminants in the SC atmosphere. The components of the VOA are: Sample Concentrator (concentrates the air sample); Gas chromatograph (GC) (separates the volatile in the air sample); Ion mobility spectrometer (detects the volatile eluted on the GC); On-line data controller and processor. The VOA automatically collects and analyses one air sample per day. Samples may be collected manually by the crew using air sampling bags. The VOA shall alert the crew when a pre-determined level for a volatile is exceeded.	m= 35 kg V= 85 l
5. Personal Air Filter	Shall be worn my CM in the event that the SC interior air is medically unsafe to breathe.	
6. Portable Breathing Apparatus	Shall be worn my CM in the event that the SC interior air is medically unsafe to breathe.	

HARDWARE	PERFORMANCE CHARACTERISTICS	PHYSICAL CHARACTERISTICS
ECLSS - Water Quality System		
1. Ion Selective Electrode Assembly (ISE)	Used to measure concentration of ammonia, silver, iodide, chloride, nitrate, calcium, potassium, and sodium ions in SC water samples. The ISE shall accept water samples from the Water Sampler and Archive. The total sample of water required for analysis shall not exceed 50 ml. The ISE shall be capable of returning sample water to the SC Water Recovery System.	Weight TBD Volume TBD
2. Spectrophotometer	Used to measure iodine, colour, turbidity, and general spectrophotometric analysis of SC water samples. The Spectrophotometer shall accept water samples from the Water Sampler and Archive. The total sample of water required for analysis shall not exceed 200 ml. The Spectrophotometer shall be capable of returning sample water to the SC Water Recovery System.	m= 50 kg V= 70 l
3. Total Organic Carbon Analyser (TOC)	Used to determine concentration of total carbon, total inorganic carbon, total organic carbon, pH, and conductivity in SC water samples. The TOC shall accept water samples from the Water Sampler and Archive. The total sample of water required for analysis shall not exceed 50 ml. The TOC shall be capable of returning sample water to the SC Water Recovery System.	m= 30 kg V= 56 l

HARDWARE	PERFORMANCE CHARACTERISTICS	PHYSICAL CHARACTERISTICS
4. Water Sampler and Archive (WSA)	Used to collect and store SC water samples for both in-flight and ground based analyses. The WSA components are: archival water sampling bags; sampling and calibration syringes. The water sampling and calibration syringes shall be capable of interfacing with the Spectrophotometer, the Total Organic Carbon Analyser, the Ion Selective Electrode Assembly, and the Water Microbiology Kit. The water sampling syringe and archival water sampling bags shall permit any water contained in them after the required analysis to be returned to the SC Water Recovery System.	m= 7 kg V= 16 l
Contamination Protection Equipment (CPE)	The CPE provides gear for protection of the crew during or after a contamination event: gloves; goggles; eyewash. The CPE does not provide supplies for clean-up of the contaminated area.	m= 4.5 kg V= 10 l
Noise Attenuation Equipment		
1. Audiometer	Tests the acuity of hearing of CM.	m= 2 kg; V= 1.5 l
2. Hearing Protectors	Inserted into the ears of CM to attenuate excessive noise levels.	
3. Noise Dosimeters	Monitor the level of noise within the SC.	

Table 2.1 Functional Hardware List

Section II

Core Module Design

Chapter 3

System Overview

3.1 DEFINITION OF THE DOCC

“The DOCC shall be a modular medical facility to maintain human health and performance in space, that is adaptable to a range of remote human habitats.”

This definition contains three terms which lead to some basic requirements:

Term 1: Modular facility

1. The DOCC facility shall be designed to exchange medical equipment, medical racks, and/or the whole medical module.
2. The “CORE” of the DOCC has been defined as a set of fundamental functions and equipment. Basic functions may not change, even if a DOCC space segment has different configurations according to different applications. However, the DOCC space segment can be modified to accommodate different scenarios and applications.
3. A standard interface between medical equipment and module should be established for modularity, for example standards for electrical connectors and fluid couplings.
4. Medical equipment should be designed based on these standards.
5. After standards are established, all engineers who will design equipment for DOCC should comply with them to ensure interchangeability and adaptability of medical equipment. These standards may be based on the existing standard such as U.S. military standards, in order

to easily apply existing medical equipment currently used in remote facilities on the Earth like Antarctica outposts.

Term 2: Medical facility

1. A DOCC shall be furnished with medical equipment including monitoring, prevention, diagnosis, treatment, countermeasure, and operational systems (not only hardware, but also software) according to applications and environmental conditions.
2. The mission scenario would vary the type and quantity of medical equipment related to the needs of “specific” medical performance. However, some basic functions can be found for DOCC, including a collection of basic functions which make up the “CORE”. Thus, the “CORE” is the minimal, optimal configuration that permits “basic” medical performance ensuring quality of the service and ability to expand easily, in order to satisfy specific medical needs.

Term 3: Remote

A DOCC, regardless of its location, shall be able to communicate with a medical centre on the Earth.

3.2 CORE DOCC REQUIREMENTS

This section details the high-level requirements for the core DOCC design. These requirements are intended to provide a general overview of the DOCC project. The aim is to outline all aspects of the DOCC system; hence, each requirement is not necessarily verifiable. Each requirement should be further specified into lower-level requirements for each particular mission or application.

High-Level Requirements List

1. The core DOCC shall support all medical conditions and events listed in the Medical Events Table in Appendix C and the psychological stressors listed in Section 1.4.3, with the indicated treatments, countermeasures, and hardware.
2. The core DOCC shall provide tools to monitor and maintain user health.
3. The core DOCC shall consist of a space segment and a ground facility, mainly, a ground control centre to co-ordinate all DOCC functions.
4. The DOCC space segment shall accommodate the medical hardware, the supplies in storage, the injured personnel, and the medical staff.
5. The DOCC space segment shall withstand load factors and vibration forces sustained during its transportation.
6. The DOCC space segment shall be designed with hardware components to be easily removed and replaced during maintenance.

7. The core DOCC shall maintain a high-speed communications and data link capable of transmitting general data, audio, video, and images between the DOCC space segment and the ground control centre.
8. The core DOCC shall allow medical staff in the DOCC space segment, to access to the expertise of medical specialists all over the world.
9. The core DOCC shall provide users of the facility with medical and technical training and support during all mission phases.

3.3 THE “BIG PICTURE”

Considering the basic requirements listed in Section 3.2, “the big picture of DOCC” is described in Figure 3.1, in order to provide an overview of the entire DOCC architecture at a glance. This figure shows that the DOCC space segment consists of two parts: the core module and the extra module.

1. Core module: The core module is a set of equipment having basic functions required by the DOCC. Even if physical configurations are different between different applications, core functions and equipment will be used in every application. The equipment is installed into the required number of racks.
2. Extra module: The configuration and number of racks in the DOCC space segment depend on the number of crew-members, the mission duration, and the environmental conditions. The extra module adds equipment and functionality to the core module in order to accommodate the different needs of different missions.

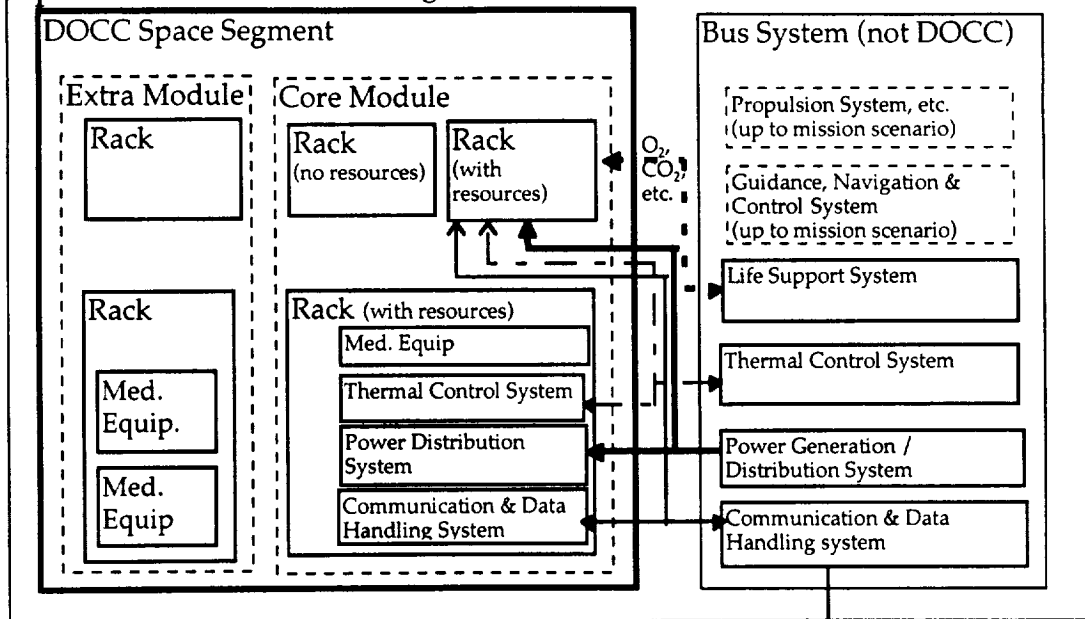
Equipment is categorised into two groups: resource dependent and resource independent. Examples of resources are electrical power, gases such as O₂ and CO₂, and data and communication links. Racks will be constructed containing either resource dependent or resource independent equipment. For example, racks containing resource dependent equipment will hold items such as the monitoring, refrigeration, and computer diagnosis systems. Racks containing resource independent items will hold equipment such as non-perishable medications, paper manuals, and bandages.

As diagrammed in Figure 3.1, resources are supplied to the resource dependent equipment, via the rack, from the bus system, such as a commercial space station in low Earth orbit or a Mars base. However, each resource dependent rack should have individual resource distribution subsystems/components. This will prevent the distribution system from impaired functioning, due to a single failure in one component that could influence not only the medical components, but also the bus system. Therefore, in the big picture in Figure 3.1, the power distribution system is shown in the core module rack as well as the bus system.

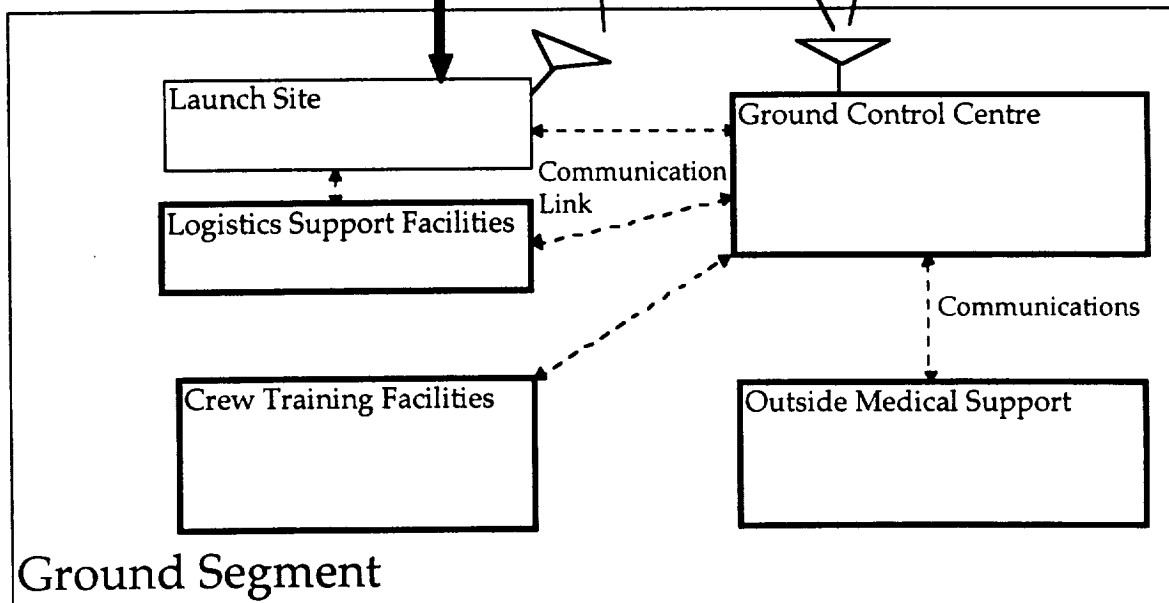
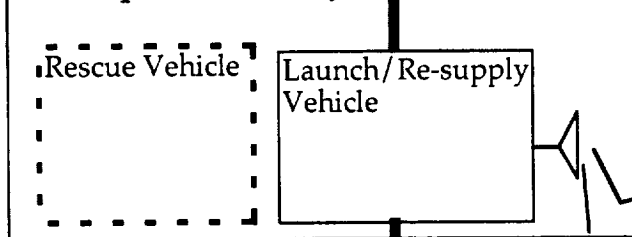
Table 3.1 allocates functions to each segment, system, and facility identified in Figure 3.1 as part of the DOCC “big picture”.

Space Segment

Space Facilities (Orbiting facilities, Mars Vehicle, etc.)



Transportation System



Ground Segment

Figure 3.1 DOCC System Block Diagram - "Big Picture of DOCC"

No.	Item / Facilities	Definition / Functions
1.	Space Segment	
1.1	Space Facilities	- Facilities attaching DOCC in space. e.g. Orbiting Facilities, Mars Vehicle, etc.
1.1.1	DOCC Space Segment	- It should have a set of medical equip. - It should consist of core and extra modules.
1.1.1.1	Core Module	- It should have common medical equipment that is required in all mission scenario. - Medical equipment in core shall include first aid, countermeasure, monitoring. - Medical equipment shall be installed to racks. - (Power, data) distribution system shall be included in DOCC, where required.
1.1.1.2	Extra Module	- It should have other medical equipment required for specific mission scenario.
1.1.2	Bus System	- Required system to operate space facilities. - Bus system supplies common resources among the space facilities such as power, data, heat, etc. - Through bus system, DOCC will communicate with the DOCC Ground Control Centre on the Earth.
1.3	Transportation System	- The methods of transportation between space facilities and the Earth.
1.3.1	Launch/Re-supply Vehicle	- To transfer DOCC itself into the space. - To support transportation of cargo (a set of equipment, or rack) for DOCC, e.g. medical equipment and consumable.
1.3.2	Rescue Vehicle	- It should have capability to return injured crew members to the Earth, when practical.
2.	Ground Segment	
2.1	Ground Control Centre	- To support DOCC. - To provide medical support to DOCC with Outside Medical Support. - To store the data of DOCC and crew members.
2.2	Outside Medical Support	- To provide on-call medical support to DOCC. - It may be hospitals, doctor, etc.
2.3	Launch Site	- To launch the DOCC and resuppliers.
2.4	Logistics Support Facilities	- To prepare logistics, e.g. consumer goods, medical equipment to exchange. - To make the logistics supply plan with Ground Control Centre.
2.5	Crew Training Facilities	- Working with Ground Control Centre. - Crew selection and pre-flight training. - Post-flight crew evaluation.

Grayed boxes are NOT included in DOCC.

Table 3.1 Function Allocation of Each DOCC Facility

Chapter 4

Space Segment

4.1 MEDICAL ASPECTS FOR SPACE APPLICATIONS

This part of the core module design outlines the medical aspects of a general DOCC for space applications. The communications and architecture aspects are described in separate sections. The contents of the countermeasure hardware is discussed in section 4.1.1. The contents of the pharmaceutical and dental kit are listed in the sections 4.1.2 and 4.1.3. To guarantee the health and productivity of the crew, a medical monitoring system is needed. This system is described in section 4.1.4. Section 4.1.5 discusses the Computerised Health Maintenance System. Telemedicine and Virtual Reality is addressed in Section 4.1.6.

The DOCC functions are driven by medical events in space, and the collection of hardware resulting from commonalities between all DOCC scenarios defines the core facility. Table 4.1 indicates which hardware and DOCC subsystems are included in the core design. All elements marked with an 'x' are core elements ('X' are core subsystems), while the ones marked with 'o' and 'O' are adaptations of hardware and subsystems respectively. The DOCC Core module is the set of functions represented by 'x'.

Table 4.1 Core Facility Definition

Hardware and Equipment	Orbit	Mars Transfer	Notes
Medical Computer System	X	O	Enhanced software/greater autonomy for Mars
- Laptop Computer - Video Monitors - Software	x x x	x x o	
Portable First Aid	X	O	
- Airway Management System - Pharmaceuticals - Standard Diagnostic Tools - Defibrillator - Crew Medical Restraints	x x x x x	x o x x o	
Standard Diagnostic Tools	X	X	More/recycled supplies for Mars Different restraints between microgravity and 1/3 g
- Blood Pressure Measurement - Ophthalmoscope - Otoscope - Digital Stethoscope	x x x x	x x x x	
Intensive Care Unit	X	O	
- Blood Pressure Measurement - Defibrillator - Electrocardiograph - Electroencephalograph - Intravenous Pump - Metabolic Gas Analyser - Oximeter - Temperature Probe - Ultrasound Device - Ventilator - X-ray Device	x x x x x x x x x x x	o x x x x x x x x o x	
Pharmaceuticals/Supplies	X	O	
- Pharmaceuticals - Intravenous (IV) Fluids - Bandages, Gauze, Drapes - Plaster, Splints	x x x x	o o o o	More/recycled/dry storage Mars More/recycled/dry storage Mars More and different for Mars More and different for Mars

Hardware and Equipment	Orbit	Mars Transfer	Notes
- Blood supply - Refrigerator - Freezer	x x x	o o o	More/different storage Mars Radiation protection for Mars Radiation protection for Mars
Surgical Equipment and Table	O	O	More extensive for Mars See Above Radiation protection for Mars Reuse/Recycling for Mars Recycling for Mars None for Orbit None for Orbit More extensive for Mars Reuse/Recycling for Mars
- Anaesthesia apparatus - Surgical glove box - Intensive Care Unit equipment - Endoscopic Surgery Kit - Refrigerator - Sharp Trash Container - Soft Trash Container - Sterilisation Equipment - Surgical Image Overlay - Surgical Instruments - Surgical Table - Urine Collection System - Body Bag	x x x x x x x o o x x x x	o x o x o o o x x o x o x	
Dental	O	O	
- Dental Ancillary Supplies - Dental Handheld Instruments - Restorative Materials - Dental Glove Box - Sterilisation Equipment	x x o x o	x x x x x	
Clinical Chemistry Analysers	O	O	
- Capnograph - Complete Blood Count Analyser - Centrifuge - Optical Microscope and Camera - Serum Multiple Analyser - Slide Staining apparatus - Urine Dipstick	o x o x x x x	x o x x x x x	
Exercise Countermeasures	X	X	
- Treadmill - Cycle Ergometer - Multi-Axial Resistive Exerciser - Lower body Negative	x x x x	x x x x	

Hardware and Equipment	Orbit	Mars Transfer	Notes
Pressure			
Countermeasures Monitoring	O	X	None for Orbit
- Blood Pressure Electrocardiograph - Metabolic Gas Analyser - Bone Densitometer - Body Mass Measurement Device	x x o x	x x x x	
Microbiology System	X	X	
- Fungal Spore Sampler - Incubator - Microbial Air Sampler - Microbiology Safety Cabinet - Optical Microscope and Camera - Slide Staining Apparatus - Surface Sampler Kit - Water Microbiology Kit	x x x x x x x x	x x x x x x x x	
Radiation Monitoring System	X	O	More extensive for Mars
- Radiation dosimeters - Extra-Vehicular Charged particle Directional Spectrophotometer - Intra-Vehicular Charged particle Directional Spectrophotometer - Radiation Area Monitors - Tissue Equivalent Proportional Counter	x x x x x	o x x x x	
Toxicology System	X	X	
- Capnograph - Compound Specific Analyser - Combustion Products - Compound Specific Analyser - Hydrazine - Volatile Organic Analyser - Personal Air Filter - Portable Breathing Apparatus	x x x x x x	x x x x x x	
Water Quality System	X	X	
- Ion Selective Electrode Assembly - Spectrophotometer - Total Organic Carbon Analyser - Water Sampler & Archive	x x x x	x x x x	

Hardware and Equipment	Orbit	Mars Transfer	Notes
Contamination Protection System	X	O	More for Mars More for Mars More for Mars
• Eye Goggles	x	o	
• Eye Wash	x	o	
• Gloves	x	o	
Noise Attenuation System	X	X	
• Audiometer	x	x	
• Hearing Protectors	x	x	
• Noise Dosimeters	x	x	

All elements marked with an 'x' are core elements ('X' are core subsystems), while the ones marked with 'o' and 'O' are adaptations of hardware and subsystems respectively. The DOCC Core module is the set of functions represented by 'x' in this table.

Table 4.1 Core Facility Definition

4.1.1 Countermeasure Hardware

A variety of exercise techniques and protocols have been devised by the American and Russian space programs. Various forms of exercise have been and continue to be studied throughout the different space programs. It has been suggested that combining exercise with one-gravity equivalent forces is the most effective way to reduce muscle, joint and bone atrophy, maintain coordination and exercise capacity [Thornton 1977] but the experiences of different U.S. and Russian long-term flights demonstrate the need for specific types of exercise during long missions [Nicogossian, Pool, Sawin 1995]. Current countermeasure devices used to prevent muscle atrophy and strength loss in microgravity include:

Cycle-like devices that can be pedalled with either the arms or the legs. Programmable constant loads ranging from 25 - 300 W at 40-80 pedal rotations/min (NASA) and the Russian VB 3 ergometer does not differ significantly in design from the ergometer used aboard Skylab. ESA developed a foldable constant load leg-ergometer with workloads of 0-350 Watt and 40-115 rpm. A computer allows pre-planned exercise programs with variable workload and speed patterns. Although the cycle ergometer is an excellent device for testing and maintaining cardio-respiratory endurance, it cannot generate forces and eccentric muscle actions in legs equivalent to those occurring during walking, jogging or running under Earth gravity. Therefore, sole use of a cycle ergometer may not adequately defend against potential losses in strength, muscle mass and neuromuscular function.

Treadmill passive and motor-driven devices are used with the application of bungee cord straps to secure the astronaut to the treadmill. Static forces up to 0.7 gravity can be produced. By means of a moveable horizontal bar and a set of expanders, the device can also be utilised for strength training. New methods for providing mechanical stability during walking and running in weightlessness need to be developed if treadmill exercise is to provide forces

to muscles and bones of the lower extremities in a similar fashion to that occurring on Earth.

Rowing Ergometers involve more muscle groups than bicycle ergometer exercise. Mechanical stresses on bones and motor skills trained are closer to normal gravity reality. From the viewpoint of countermeasures, the exercise is something close to lifting weights. But if strength training is the goal, better simulation and less weight can be achieved by choosing simple strength training devices [Wegmann, Essfeld, Jessl 1988].

Motomir Ergometer involves more muscle groups than bicycle ergometer. It is a motor driven device which allows velocity controlled strength and endurance training in a closed kinetic chain of either the legs or arms in isometric, concentric or eccentric work mode. This device can also be used for in-flight diagnosis of neuromuscular functions [Bachl 1996].

YoYo Ergometer is a gravity independent strength training device with a flywheel that produces resistance. Both concentric and eccentric muscular actions can be performed. Adaptations similar to those achieved by traditional weight training [Berg, Tesch 1994]. Development of protocols and procedures to do endurance training is in progress.

Strength training devices that have also been regularly used during previous spaceflights ranged from simple chest expanders to rope and pulley machines to exercise muscles of the upper part of the body. Their usefulness has been limited since quantification of forces can neither be controlled nor measured. A number of isokinetic devices including pneumatic devices are capable of providing the required exercise profiles but are usually too bulky to be launched. A disadvantage to the use of isokinetic exercise as a countermeasure is that it will not mimic the natural neuromuscular activity in normal gravity conditions [Convertino, Sandler 1995].

Electric stimulation is an attractive operational option for counteracting muscle atrophy because space travellers could undergo treatment while performing daily operational tasks [Dudley et al. 1989].

Penguin suit designed to produce long-duration loadings on skeleton and antigravity muscles may also help to redistribute fluids towards the legs [Diamandis 1992].

Artificial gravity produced by a centrifuge is costly and complicated and include symptoms of motion sickness but it could prevent many other physiological deconditioning symptoms [Koslovskaya 1996].

Anti-gravity suits applies positive pressure over the lower limbs and thus counteract the pooling of blood to the dependent part of the body upon return to gravity environment.

Lower Body Negative Pressure (LBNP), by applying a relative negative pressure distal to the iliac crest, blood volume are pooled the lower limbs. This simulates the upright posture in 1 g environment and might restore plasma volume and condition the cardiovascular system during spaceflight.

Twin bicycle [Antonutto 1994] or **Twin running system** [Atkov 1996] move on the inner wall of a cylindrical surface (spacecraft module). With this device two subjects can develop enough speed to generate centrifugal acceleration equivalent to 1g at their feet. Coriolis cross-coupled accelerations and subsequent symptoms of motion sickness could pose a significant disadvantage if the radius of the cylinder is too small [Convertino, Capelli, Di Pampero 1995].

4.1.2 Pharmaceutical Kit

As mentioned in Section 1.7, the type of drugs for the pharmaceutical kit depends upon the shelf life and drug absorption and elimination in microgravity, and predictions of which medical situations are likely to arise. Since it is known that the absorption of oral drugs is sensitive to gastrointestinal motility, which may be altered in space, one should consider intravenous and intramuscular administration in space for some drugs [Barratt, 1996]. Also the pharmacodynamics of drugs and biological materials may be different or altered in a microgravity environment. However, no extensive study on this has been found.

The drug types listed below are based on [Space Shuttle Program Medical Checklist, 1990] and are categorised in the different medical events that may occur during space flight:

- Anaesthetics
- Anti allergic reaction
- Anti altitude sickness medications
- Anti constipation
- Anti diarrhoea
- Anti emetics
- Anti skin rash and itching
- Antibiotics
- Antiseptics
- Decongestants
- Ear & eye medications
- Heart medications
- Muscle relaxants

- Pain killers
- Pharmaceuticals for countermeasures (see Section 1.6.9)
- Psychotropics
- Sleeping pills

Blood storage: For emergency cases, crewmember blood storage may be necessary. A small pre-flight crewmember's erythrocyte donation will be needed and stored at - 196° C in a nitrogen cooled freezer. The shelf life will then be 10 - 15 years instead of 45 days at + 4°C. When needed, the blood supply can be defrosted with warm water within 15 minutes. Another option might be the storage of a cross-linked stroma-free haemoglobin solution. These can be prepared and also have a long shelf life. This possibility is still being studied [Hagenouw,R.].

The bandages kit should contain items for wound coverage, collagen pads for burns, adhesive tapes, bandages, and other adjunctive items.

4.1.3 Dental Kit

As explained in Section 1.8 the dental kit consists of two parts, namely the equipment part and the consumables part. The table below lists the equipment and consumables for the dental kit.

Dental equipment	Functional description
Dental rotary tool with various heads	The rotary tool is needed to support a drill and other dental heads
Extraction instruments	These instruments are used to extract teeth if necessary
Mirror	Mirror is needed for observation of teeth
Dental Consumables	
Orangewood sticks	
Syringe	Syringes are needed to inject fluids
Filling and crowns	These are needed to fill and cover dental disorders
Tweezers	
Cotton pellets	

Table 4.2 Contents of Dental Kit

4.1.4 Monitoring System

The Medical Monitoring System is part of the Health Maintenance System in order to guarantee the health and productivity of the crew. To accomplish this

goal it is appropriate to use sophisticated monitoring procedures and equipment. The medical data collected after each monitoring procedure have to be implemented in the computerised medical record system, CHMS (see Section 4.1.5.1). Adequate action has to be taken based on the results of the medical monitoring procedures concerning countermeasures (see Section 1.6) and treatment.

Also part of the Medical Monitoring System in conjunction with the computerised inventory system is diet-monitoring (see Section 4.1.5.4). It is not only to keep track of diet products but also to use as a diagnostic tool (see Section 1.3).

4.1.4.1 Medical Monitoring

In order to design a medical monitoring system it is necessary to identify the medical requirements. It is of great importance to isolate physiological parameters that are affected by the environment in consideration. The next step is to extract information about these physiological parameters by means of medical examination methods and to correlate these with the required medical hardware.

Principle medical examination methods for physiological and psychological parameters concerning long term spaceflight are (see also Sections 1.3.3 and 1.4):

- *Blood-Analysis*: change in red blood-cell mass and shape, loss of electrolytes, infections more likely, immune-system (e.g. the number and the proliferation of T-Lymphocytes is reduced, the number and activity of natural killer cells (Cytotoxic) is reduced), hormonal changes (e.g. increase in Insulin, TSH and of stress hormones like Cortisol), calcium metabolism (e.g. Vit. D₃, PTH), effect of radiation (e.g. Testosterone, Oestrogen, TSH, T₃, Complete-Blood-Count CBC)
- *Faecal/Urinalysis*: infection of the urinary tract, bacteria of the gastrointestinal tract
- *Physical/Dental-Exam*: ENT (Ear, Nose, Throat)-infections, ENT-foreign body, skin infection, eye-foreign body, eye infection, peripheral vascular disorders, radiculitis, sleep disorders (with an Electroencephalogram-EEG), and cavities
- *Bone density*: decrease in Bone-Mineral-Density (BMD)
- *Electrocardiogram*: (ECG): arrhythmia, heart rate, cardiovascular deconditioning (cardiac output, polarisation state, PR and QT-intervals)
- *Echograph*: cardiac size and volume (volume increase), intracardiac blood circulation (higher velocity of blood flow), imaging of internal organs especially of the kidneys (higher risk of kidney stones)
- *Psychological*: stress, depression, isolation

- *Fitness-check*: (together with countermeasures, see Section 1.6): muscle strength (magnitude of force, endurance of force, speed/velocity of the force), cardiovascular (CV)-deconditioning (aerobic capacity)

It is necessary to define the medical hardware necessary to conduct the required medical exams (Table 4.3 and Table 2.1).

	Bone/ Muscle	CV-System	Blood-Analysis	Radiation	Physical/ Dental exam
Clinical Lab-Unit	calcium metabolism		CBC with differential, Microbiological, Immunological, Haematological	specific screening	general health
Medical Routine Equipment		blood pressure			ENT, eye, temperature, blood pressure, skin, height, Neurological exam
Body-Mass Device (BMD)					body mass
Bone Densimeter	BMD				
ECG		heart rate, bioelectrical activity of the heart			general health
Echograph	muscle and joint tissue	blood flow, visualisation of the vessels			internal organs
X-ray	fractures				lungs
Radiation Monitoring				individual dose	
Fitness- check	muscle strength	aerobic capacity			

Table 4.3 Required Medical Hardware for the Medical Monitoring System

To finally come up with a monitoring routine, one has to decide about time frames for the specific examinations (see Table 4.4).

Frequency of exam	two weeks	one month	as required
full blood-analysis		X	
limited blood-analysis	X		
physical/dental-exam	X		
faecal/urinalysis		X	
bone densiometer		X	
ECG	X		
Echograph		X	
X-ray			X
fitness-check		X	
psychological		X	

Table 4.4 Monitoring Routine

From a medical and practical point of view it is not necessary to conduct a full blood analysis every second week. Therefore there are two different kinds of blood analysis:

- Limited blood-analysis: Complete-Blood-Count (CBC), MCV, HCT, MCHC, WBC, Pet, RBC.
- Full blood-analysis (additional to the limited blood-analysis): Electrolyte (Na, CL⁻, K⁺, Mg²⁺, Ca²⁺, P⁺, CO₂), urea, glucose, creatinine, hepatic enzymes.

Although not included in the actual DOCC hardware, there are at least two new diagnostic techniques that will surface in the next view years. The first one is a functional-MRI (fMRI) with which it is possible to visualise functions of specific physiological processes like metabolic rate [McVeigh 1994]. A second one is Magnetoencephalography (MEG) [Reite 1996]. This MEG can readily outperform any EEG but is still in the experimental phase. Both techniques can be used not only for pre-flight screening but also for monitoring procedures (neurological exam, cardiovascular deconditioning, metabolic rates) during the flight.

4.1.4.2 Radiation Monitoring

There are several different kinds of radiation sources in space:

- Van-Allen Radiation Belts (the inner one is dominated by protons, the outer one by electrons)
- Solar Radiation (mostly protons, X-ray and UV)
- Galactic Cosmic Radiation (GCR, including highly energetic nuclei-so called “High Z and Energy-HZE” particles)

The different kinds of radiation have quite diverse effects on biological systems. To take this into account, it is necessary to multiply the measured radiation dose [rad] with a weighted factor called the “Radiobiological Effectiveness RBE” (Table 4.5). The unit of the weighted radiation dose is the *rem* (“roentgen equivalent, man”).

kind of radiation	RBE
γ - rays	0.5 - 1
Electrons (e^-)	1
Protons (p)	2
Neutrons (n)	2 - 10
Helium-Nuclei (α)	10 - 20

Table 4.5 Relation between the kind of Radiation and the RBE [Tascone 94]

The primary effect of increased ionising radiation (Table 4.6) is the energy deposition in molecules (see Section 8.2.2.1). A biological cell consists of several different molecules and is therefore indirectly affected by the ionising radiation.

Not every cell is affected in the same way by ionising radiation. The lower the grade of differentiation and the higher the mitotic reproduction rate the more they are affected by radiation. Critical for humans are blood cells and bone marrow cells.

Average dose on Earth [rem/y] ¹	Intercontinental Flight [rem] ¹	LEO [rem/y] ¹	Van - Allen crossing [rem] ²	Mars-Transfer [rem/y] ³	Mars-Base [rem/y] ³
0.17	0.004	30 (without solar flash)	< 0.5	50	< 25

1. [Tascone 1994], 2. [ISU 91], 3. [ACTA 1993]

Table 4.6 Overview about Different Radiation Environments

Because of the inherent danger of increased ionising radiation and the accumulative effect to biological systems, it is necessary to control the individual radiation dose and to set limits for that. To monitor the different kinds of radiation and to determine the individual dose, it is necessary to use several different radiation - detector devices [CHECS 1996]:

- passive-system: plastic nuclear tracking detector, emulsions, thermoluminescence detector
- active-system: multiple proportional chamber, semiconductor detector

The passive-system is the individual radiation-batch for each crew member. It is small and lightweight and guarantees permanent radiation monitoring. The

disadvantage of this passive-system is that there is no information concerning time-resolution. Furthermore, the system is not able to identify the incident particle and therefore it is not possible to extract the RBE from this measurement.

The active-system consists of three parts [CHECS 1996]:

- Extra-Vehicular-Omnidirectional-Charged-Particle-Spectrometer
- Intra-Vehicular-Omnidirectional-Charged-Particle-Spectrometer
- Tissue Equivalent Omnidirectional Proportional Counter (TEPC)

The omnidirectionality for the spectrometers is necessary because the GCR (unlike the solar radiation) is an isotropic radiation. The signal of the “Charged-Particle-Spectrometer” is a function of time, charge, energy and direction. Therefore the system is capable of identifying the incident particle and of setting up a time correlation of events. Together with the passive-system it is possible to determine the individual weighted dose [rem]. The TEPC measures the radiation dose at the cell level (2 micron site) to get a better impression of the biological efficiency of the absorbed radiation.

The use of extra- and intravehicular radiation measurements also allow the determination of secondary particle processes (e.g. neutron production due to interaction of the primary radiation with shielding material).

It is reasonable to position a number of “Charged-Particle-Detectors” and some passive-detectors in sensitive areas of the space-vehicle like the sleeping-accommodations or research facilities.

In addition to this physical measurement of the radiation dose, it is also possible and necessary to exam the direct effect of the radiation on the human body. One can see the effect of radiation by doing a blood analysis (CBC, Hormones (Testosterone, Oestrogen, TSH, T₃)).

4.1.4.3 Personal Position-Monitoring System (PPMS)

The Personal Position-Monitoring System (PPMS) can be either an active system (semiconductor signal-emitter) or a passive system (semiconductor signal-receiver). Both systems are based on semiconductor microchips with the ability to emit or receive terahertz signals. Included in the semiconductor laser is a microchip that encodes and controls the signal-emission. The advantage of this active system is that it allows real-time position sensing of each crew member. Included in the semiconductor detector is a microchip that controls the location, time, data transfer and storage (Table 4.7).

	Passive system	Active system
Time resolution	weekly readout	real-time
Storage capability	yes	no
Data transfer capability	yes	no
Signal processing	yes	no

Table 4.7 Comparison of the Active and Passive Position Monitoring

The positioning of detectors/emitters throughout the spaceship is necessary to guarantee appropriate surveillance.

Because this “Personal Position-Monitoring System” is only a microchip, it can be easily incorporated in the individual radiation-batch. In addition, the real advantage of the positioning system is in connection with the radiation monitoring system. It allows a better qualification of the individual radiation dose.

The Radiation-Batch/Personal Position-Monitoring System includes also a small device (diaphragm) that can measure the extent of decompression events (very important for treatment) either by setting a threshold or by using a stress sensitive technique.

4.1.4.4 Extra Vehicular Activity (EVA) Monitoring

The medical monitoring system for EVA will be the same as the present system in use. The physiological important parameters and the appropriate monitoring equipment is:

- ECG: heart-rate, bioelectrical activity of the heart, metabolic rate
- radiation-batch: individual dose
- pulse oxymeter: pulse, oxygen saturation
- gas analyser (O₂, CO₂): respiration
- blood pressure-watch: blood pressure

To collect these data, a centralised Patient Status Monitor-Unit (PSM) will be used [Schenker 1996]. Every data acquired during EVA is transferred directly to the computerised medical record system.

4.1.5 Computerised Health Maintenance System (CHMS)

The software of the Computerised Health Maintenance System (CHMS) will be described in this section.

The software of the CHMS will have to handle several functions, namely:

- Computerised medical records
- Advanced diagnostic and monitoring capability

- Access to electronic medical literature for education and reference
- Medical inventory system

4.1.5.1 Computerised Medical Record System

The medical record system will store:

- previous examination results: A standardised method for writing medical reports will be utilised. Previous vitals, results of tests, and diagnostic imaging will also be stored. It will also include previous treatments and results of treatment, including adverse effects of any treatment. These results will be useful for trend analysis.
- samples of DNA and pertinent family history: This will be used to predict disease states and other medical problems.

The data will be stored in an encrypted format and only certain personnel will have access to different levels of information. The system will also have a connection to all of the data acquisition devices. This will allow the computer to perform some pre-analysis of the information and will allow previous test results to be easily compared. Data from previous tests may be transferred for archive purposes after it is no longer needed.

Entry of the medical information system may be made in several ways:

- Keyboard/voice entry of plain text in a standardised format.
- Data entry in response to a computerised prompt (e.g. “Do you have right lower flank pain (yes/no)” or via standardised survey of medical problem forms. This will permit people with very little medical training to take a medical history.
- Data entry directly from a medical device (e.g. ECG, X-ray)

4.1.5.2 Advanced Diagnostic and Monitoring Capability

- The Diagnostic Medical System (DMS) will provide the following support to its users:
- Interpretation: Analyse medical data, medical tests, and physical examinations. For example, the system will be able to interpret ECGs and lung sounds for diagnostic purposes. The system will also be responsible for extended monitoring of patients and for alerting personnel of the occurrence of any abnormalities.
- Assisting and Guiding: The DMS will be used to help personnel select which medical tests should be performed. The DMS will also assist personnel in performing medical examinations by indicating which exams should be performed and in conducting medical histories by prompting personnel to ask certain questions.

- **Critiquing of Decisions:** The medical system will critique a physician's orders and offer advice on elements such as countermeasures, drugs, etc. This system will act as a second opinion. However, the physician will always have the final word on any treatment that will be delivered to the patient.
- **Treatment Management:** Management protocols will also be programmed into the system. The computer will also be aware of equipment usage and requirements so that equipment treatment can be scheduled and made available when required. For example, countermeasures will be scheduled so that personnel can use the countermeasures apparatus at different times.

The above diagnostic and monitoring requirements will be met with a variety of Artificial Intelligence (AI) and algorithmic programming techniques.

4.1.5.3 Access to Electronic Medical Literature for Education and Reference

The CHMS will allow users to have access to current on-line medical literature. This will allow users to have the most current medical information for both the treatment and prevention of diseases. Access to this resource will be controlled by the ground segment. This information will include access to computerised medical literature (e.g. MEDLINE), computerised medical journals, etc. However, most literature searches should be done via personnel on the ground because the flight crew will probably not have time to perform medical literature searches.

The CHMS will also be utilised as an educational tool by medical and non-medical personnel to update training and keep the current skill level at an adequate level. Several on-line tutorials which will utilise virtual reality tutorials will be provided to the users of the CHMS. There is also the potential for the data from the CHMS to be used as a source of research for educational material for ground segment investigators.

4.1.5.4 Medical Inventory System

The inventory system will contain a database of all pharmaceuticals and medical hardware, both recyclable and consumable. Usage of these resources will have to be logged into the CHMS via either a bar code system or via a keyboard/voice entry system. This will allow tracking of usage of pharmaceuticals and medical devices. In addition, shelf life and quantity remaining will also be entered in the system. The system will also provide a warning regarding potential drug interactions and possible adverse side effects before any pharmaceutical is dispensed.

4.1.5.5 Notes about the Construction of the CHMS

The software of the CHMS will be designed so that procedures may be easily updated and edited without drastically affecting the program. Modules of the

program should be clearly documented with the function of the module, the inputs, and outputs of the module.

All software and hardware designed for the DOCC should be tested extensively by a group unrelated to the designers and then in real-time settings such as in a medical facility that deals with medical problems in space environments. This will assure that no bias enters into the test procedures and that the system is tested in a real-time environment before it is actually used on the DOCC. In addition, the CHMS should be designed in an incremental manner; the system should, first, be capable of handling problems in simple environments, with levels of complexity being added as other problems are solved. The incremental design of the system can be achieved by rapid prototyping and visual programming software technologies.

The cost of designing the CHMS may be reduced by using existing software models and operating systems that are successfully used in existing Earth applications. Designing a computer system from the very basics will be very time consuming, expensive, and potentially incompletely debugged. Therefore, it is suggested that industry standards be adopted to decrease development time and costs.

4.1.6 Telemedicine and Virtual Reality

This section describes the telemedicine, virtual reality and artificial intelligence parts of the DOCC.

4.1.6.1 The DOCC Telemedicine and Virtual Reality System

Telemedicine and Virtual Reality (VR) are key elements to the Computerised Health Maintenance System (CHMS). Although the medical personnel on the DOCC will be highly trained in all fields of medicine, they will not be able to give the best medical care to every medical event without consultation with other specialists. The telemedicine and VR system will help diagnose and treat the patient. In addition, the system will also allow the medical personnel to practise their skills. This will require a good network link to the ground station medical centres. The components of the telemedicine and VR systems are described below:

- Operating station
- Computer models of the anatomy and the surgical instruments
- A Head Mounted Display with a see-through option to display data
- Head and gloves position tracking devices which include algorithms for tracking the position of the users head and hands. It shows the representative view as well as collision detection capability.
- Behaviour modelling which models the human body as a set of flexible, compressible, and stretchable organs that vibrate, pulsate and move

- Force feedback system which will simulate resistance when force is applied to the object.
- Position tracking system for the surgical instruments
- Software to control the interaction between the environment and will update the visual and force feedback systems.

4.1.6.2 The Challenges of Realistic Virtual Reality

- Movement of anatomy
- Realistic landscapes
- Introduction of varying pathology
- Interaction of instruments
- Deformation, dissection of anatomy
- Tactile force feedback
- General anatomical setting
- Expert system monitoring, feedback evaluation
- Non-prohibitive cost

4.1.6.3 Artificial Intelligence in Medicine

Artificial Intelligence (AI) is defined as:

... the part of Computer Science concerned with designing intelligent computer systems ... that exhibit behaviour ... [such as] learning, reasoning, and problem solving.

Medical AI programs differ from algorithmic approaches because they are based on symbolic models of disease entities and their relationship to patient factors and clinical manifestations. This symbolic reasoning ability means that AI programs are more powerful because they take a generalised approach to solving a problem.

There are several advantages to using computer programs to aid interpretation of medical data. The first reason is to improve the *accuracy* of clinical diagnoses. Computers are systematic and can arrive at the same diagnosis regardless of how many hours they have worked. In addition, programs can be structured so that they *integrate* data from diverse sources such as existing databases containing patient records. Computers are also viewed as a method of *improving* the cost efficiency of *test and therapy selection* because they can be programmed to “reason” about time and cost factors. Finally, the integration of computers and medicine is an opportunity to *improve* our *understanding of medical knowledge* and the *medical consultation* process. A better understanding of the relationships between existing knowledge is often

obtained when medical knowledge is entered into a computer-based medium because it must be well thought out [Shortliffe et al., 1979]

A variety of medical expert systems have been successfully developed [Shortliffe, 1974] and [Georgeson, 1992]. These medical expert systems may be readily adapted for use on the DOCC. In addition, a number of medical neural networks have also been created to deal with medical scenarios [Forkheim et al., 1995] and [Casaleggio et al, 1991]. Many of these existing AI applications can be adapted for use in the DOCC.

The system will use AI programs to interpret the clinical data. Some of the medical data will be collected continuously for prolonged periods, e.g.) EKG data during EVAs. Using a computerised approach to analyse the data and indicate which parts of the data appear abnormal will free up personnel for other duties. The computer will continually screen monitoring data and sound an alarm with the an abnormality is found. Occasionally, the performance of the computer will be monitored by the ships medical personnel.

Software agents are another area of AI which can be used. These are programs that learn to predict needs and behaviours of the users. The program can learn to perform common tasks and can infer new tasks based on this information.

4.1.7 Medical Architecture Drivers

While some aspects of DOCC architecture are driven by specific mission requirements and scenarios, many of the medical functions, hardware elements and subsystems remain common and scenario independent. Differences are found mostly in the Mars applications, and might include expanded capabilities, increased volume for supplies, increased size or mass.

The specific medical procedures and requirements occurring in spaceflight heavily influence the internal architecture and layout of the facility. Contained within the core module are the emergency and routine medical treatment facilities, the countermeasures facilities, and the medical science equipment. Careful planning will maximise efficiency of the DOCC by making use of equipment and space for multiple purposes. Table 4.8 gives guidance for the internal arrangement of hardware, based on medical needs. In this matrix, an 'x' indicates a need for the two hardware systems to be connected electronically. A shaded box with an 'x' indicates that the two components should be physically close within the DOCC, while an '0' indicates that the two should be far apart from each other.

One of the developing objectives throughout space and technological projects is standardisation of interfaces and the development of protocols, the current state of which is presented in this chapter along with the emerging standards of the space business.

A further important issue when considering the passing of medical data between the facility and the ground station is the issue of security, and in considering this, traditional and emerging data protection and encryption methods are discussed.

A powerful aid to diagnosis and treatment of medical problems is image processing. This can range from the simple, effective display of medical imaging data, to more complex, three-dimensional reconstruction techniques and virtual reality facilities. Various image analysis techniques are discussed here, within the context of medical requirements.

Data handling and processing such as this requires a competent computer system including adequate processing power and efficient and robust data storage means. Computers and system architecture are discussed including protocols, hardware and software recommendations.

4.2.1 Bandwidth Requirements

The bandwidth is a vital resource in the management of DOCC activities. It determines the quantity of information that the module can send to the ground station in the unit of time.

The size of bandwidth depends on the antennas and the frequencies used for the transmission of data. The higher the frequency the larger the bandwidth. Depending on the frequency used, the bandwidth will have a certain dimension, and the transmission of data will be limited to the corresponding maximum data rate. The typical bandwidth sizes can be found in the following Table 4.9.

Type	Bandwidth size
Fiber optics	5-30 Gb/s
RF (orbital station)	~ 100 Mb/s
RF (lunar)	~ 10 Mb/s
RF (mars)	< 100 Kb/s

Table 4.9 Typical Bandwidth Sizes

Since the bandwidth is a limited resource, it should be clear how much of its capacity is required to transmit the different data types that occur during a session of remote medical assistance.

The following paragraphs detail the characteristics of these data types, in terms of dimension and required data rate. It is assumed that the system implemented in the DOCC facility has the same characteristics of a

“terrestrial” multimedia system, as shown in the chapter treating the hardware configuration.

The following Table 4.10 presents the media types, associating them to a sample format, data volume and transfer rate.

Media Type	Sample Format	Data Volume	Transfer Rate
Text	ASCII	1 MB / 500 pages	2 KB/page
B/W image	G3/G4-FAX	32 MB/500 images	64 KB/image
Colour image	GIF, TIFF	1.6 GB/500 images	3.2 MB/image
Colour image	JPEG	0.2 GB/500 images	0.4 MB/image
CD music	CD-DA	52.8 MB/5 min	176 KB/sec
Consumer video	PAL	6.6 GB/5 min	22 MB/sec
High quality video	HDTV	33 GB/5 min	110 MB/sec
Speech	M-LAW, LINEAR	2.4 MB/5 min	8 KB/sec
Speech	ADPCM, MPEG audio	0.6-0.2 MB/5 min	2-0.6 KB/sec

Table 4.10 Media Types, Sample Formats, Data Volume and Transfer Rate

4.2.1.1 Text

A page of ASCII text has an approximate size of 2 Kbytes, thus the transmission of textual information does not present problems concerning the bit rate.

4.2.1.2 Images

The images play an essential role in the DOCC activity, since they represent a highly effective way to analyse the patient’s physical conditions.

The size of images can vary greatly, depending on the medical devices that produce the image and the format of the image itself. As can be seen in Table 4.10, GIF and TIFF formats produce images with bigger size than JPEG does, due to different levels of compression (see Section 4.2.2 about data compression).

The size in bits of a picture can be obtained through the following formula :

size(in bits) = height (in pixels) x width (in pixels) x number of bits per pixel.

For example, an image of 800x600 pixels will be composed of 480,000 pixels; if it is a black & white (B/W) image every pixel will be described by 1 bit giving the size of 480,000 bits, or ~ 60 Kbytes. If the same image has 256 levels of grey (i.e. 8 bits per pixel) its size will be ~ 480 Kbytes.

Most medical images require the full colour option (~ 16M of colours, corresponding to 24 bits per pixel). An image of 800x600 pixels with 16M colours has the size of ~ 1.4 Mbytes.

Computer tomography image : 512x512 pixels, 12 bpp; Size ~ 400 Kbytes

Magnetic Resonance image : 2K x 2K pixels, 16 bpp; Size ~ 8 Mbytes

X-ray image : 2K x 2K pixels, 12 bpp; Size ~ 6 Mbytes

clinical or histopathology image : 800x600 pixels, 24 bpp; Size ~ 1.4 Mbytes

4.2.1.3 Audio

In contrast to the previous data types, audio has the characteristic to be time-continuous, in the sense that it is in relation with the real-time scale. An audio stream must be transmitted at a bit rate high enough to allow its correct reception.

Voice quality audio (speech) requires ~ 64 Kb/s, but this bit rate can be reduced to a few Kb/sec using techniques like PCM (Pulse Code Modulation) or advanced PCM (ADPCM, delta PCM). This kind of quality audio will be used for voice communication and video-conference.

A CD-DA (Compact Disc - Digital Audio) quality audio transmission (44.1 KHz, 16 bit) requires a data rate of 1.4 Mb/s. High quality audio will be used for heart and lungs sounds, not necessarily in real-time. One minute recording of these sounds occupies 84 Mbytes of memory, in the case of delayed transmission.

4.2.1.4 Video

The management of video includes the handling of image and audio data. In addition to the time-dependency of audio data, video has to reflect the time-dependent sequence of images. The atomic constituents of video data are frames, which are closely related to image data.

Representing video data requires effective compression techniques as it leads to a huge amount of data. For example, regular motion video requires 30 frames per second. With no compression :

- NTSC quality video (512 x 480 pixels, 8 bpp) results in 1.92 Mb/frame, that is 57.6 Mb/s;

- HDTV quality video (1024 x 2000 pixels, 24 bpp) results in 48 Mb/frame, that is 1.4 Gb/s.

With the present compression techniques the transmission of digital TV requires only 6 Mb/s.

Anyway it should be considered that for slow movement video, a rate of 15/20 frame/s could be acceptable.

Videoconference can be provided at different levels of quality, ranging from the very low performance at less than 100 Kb/s (Internet like) to higher quality at 300 Kb/s or more.

4.2.1.5 Dynamic Bandwidth Allocation

Since the DOCC module does not have its own communication hardware, (antennas) all its data flow will pass through the main spacecraft/station. This means that the data rate of the communication between Earth and DOCC will be limited by the fraction of bandwidth that the main system can grant at this time.

The necessity to have a sufficient bandwidth for the medical data transmission poses the problem to establish a protocol for the bandwidth allocation between the DOCC module and the host structure.

The allocation of bandwidth to DOCC will be dynamic, depending on the traffic generated and the importance of data to be transmitted. The policy of assignment will be regulated by specific algorithms.

The protocol of dynamic bandwidth allocation will make provision for an emergency procedure. In the case that very important medical data must be transmitted as soon as possible, the DOCC will be provided with the maximum available bandwidth, having the highest priority on other tasks.

Possible algorithms for the management of dynamic bandwidth allocation could be rate-based, buffer-occupancy based or predictive buffer-occupancy based.

In the first algorithm the allocation decisions will be functions of the actual incoming and outgoing data rates from the DOCC module. The second algorithm will base its decisions on the amount of data waiting in the buffer to be transmitted. The last one will attempt to predict the amount of buffered data for a future time-instant, and determine the allocation accordingly.

4.2.2 Data Compression formats

The amount of information in an image is very high. Even with the highest bit rates available (~150 Mbps), it is not possible to transmit audio, images or videos efficiently without compressing the information. As a consequence,

there exist a lot of different compression codes for different tasks. Although, this standards can change in the time-frame of the missions (2015 or 2020) they could nevertheless be used in space applications. First, telemedicine is just a growing discipline which has to start with some given technical possibilities and second, space programs are normally planned over several years and the possibility to implement the latest technology is not given.

First, some common features and capabilities of three compression codes (JBIG (Joint Bilevel Image Group), JPEG (Joint Photographic Experts Group) and MPEG (Moving Pictures Experts Group)) will be explained. Next, the special possibilities and constraints of these compression codes will be discussed. The first two have been created for compressing still images and MPEG has been developed for video/audio compression. Finally, the effectiveness of these compression codes in respect to the DOCC-project and telemedicine in general will be discussed.

4.2.2.1 Common Features of the Compression Codes

In an image and in video, there is a lot of redundancy in the information that has to be transmitted. The basic idea of all compression codes is to minimise the needed data rate by decreasing the redundant information in an image. The compression codes can be divided into two general categories: lossless and lossy compression.

With lossless compression the output image will be digital identical to the input image. There is no loss of any information. Instead of sending pixel by pixel, the compression algorithm creates information about groups of pixels e.g. next four pixels have value 7 then nine pixels have value 3. This is a simplified explanation of the algorithm structure. With lossless compression codes a compression rate of about 2:1 is possible.

This means that the compressed file has half the size of the uncompressed file. It is not possible to increase this compression ratio with future techniques and better algorithms because only the redundancy in the image is used and the amount of redundancy will not change.

Lossy compression takes advantage of the fact that the human eye perceives small colour changes less accurately than small changes in brightness. Therefore, most lossy compression codes remove small changes in colour (or grey-scales) and bigger compression rates are possible (up to 20:1) without much loss in image quality. These compression codes are able to transmit “visual lossless” images.

In videos there is another source of redundancy that can be used for compression. The differences from one frame to the other are normally small. The compression algorithm can therefore take advantage of the unchanged patterns and only send the information that changed. This method is very effective in sequences of slow movements. When there occur fast movements there are more changes and therefore more information has to be sent. A

normal video mode uses about 30 frames per second. If it is necessary, (e.g. limited bandwidth) the number of frames can be reduced to 15-20 frames per second. In this mode however, the movements are no more smooth.

4.2.2.2 Compression Codes

In this section we will discuss three relevant image and video compression codes for the DOCC project and we will also have a short look at the capabilities of actual audio compression algorithms.

A) Joint Bilevel Image Group (JBIG)

The Joint Bilevel Image Group (JBIG)-Standard is the first compression code we want to discuss. The International Organisation for Standardisation (ISO) together with the International Telegraph and Telephone Consultative Committee (CCITT) formed in 1988 a group (JBIG) which should create a standard for the progressive coding of bilevel (two-tone, black/white) images. The JBIG standard is nearly finished. JBIG is a lossless compression code. Although, JBIG was developed for bilevel coding, it can be used for grey scale or even colour images. In this mode each bit plane of the image depth is considered as an independent bilevel image. Normal colour images have a depth of 24 bits (one byte for red, green and blue). With the JBIG standard it is possible to compress grey scale images required for medical purposes (image depth of 12-16 bits).

Another feature of the JBIG standard is progressive coding. The image is coded as a low-resolution image followed by a sequence of "delta"-files. Each "delta"-file allows to double the resolution. In the JBIG algorithm the number of doublings is a free parameter (typical values are 4, 5 or 6). The possibility of progressive coding allows to browse through low-resolution images and choose the needed picture and download it in high resolution. The progressive coding is only an advantage on medium-rate links (between 9.6 kbps and 64 kbps). With slower bit rates it takes too long to send pictures interactively, for faster bit rates the user will not realise the progressive coding scheme. The compression rate is about 2:1.

B) Joint Photographic Experts Group (JPEG)

The Joint Photographic Experts Group (JPEG) started its work also in 1988, chartered by ISO and CCITT. Its task was to develop a general-purpose standard suitable for as many applications as possible for continuous-tone colour still image compression. It was not possible to satisfy the requirements of all still image applications with one algorithm. A solution was found with four different modes of operation:

- Sequential DCT-based (Discrete Cosine Transform)
- Progressive DCT-based
- Lossless
- Hierarchical

The sequential DCT-based mode is the standard way of coding and decoding the images. The progressive DCT-based mode uses a different procedure for encoding the image that allows to build up the image in a progressive procedure (useful for medium-rate links). The lossless mode allows to have no data loss and about the same compression rates as for JBIG is possible. Medical images need a depth of 12 to 16 bits. JBIG was not specially designed for images with a big depth but JPEG was planned for colour images (24 bits). Therefore the JPEG suits better for our medical purposes than the JBIG standard. The hierarchical mode is a different approach to get progression. All three of the above methods can be used as a basis for the hierarchical mode. This means that it is possible to have a progressive transmission of a lossless image. This feature could be very useful for the DOCC project. The compression rate for JPEG is in the range of 10:1 to 20:1. In maximum it is possible to have a compression rate of 24:1. There also exists a further development of JPEG for moving images: Motion JPEG (M JPEG). It seems that M JPEG at low compression rates (3:1 to 5:1) is superior to MPEG. By compression rates above 20:1 degradation becomes very visible. The motion JPEG is not an ISO-standard, therefore it is not possible to share these images between hardware of different manufacturers.

C) Moving Pictures Experts Group (MPEG)

The Moving Pictures Experts Group (MPEG) develops an ISO-standard for audio/video compression. The MPEG-standard was divided into three different phases.

MPEG 1 was primarily developed to compress video for digital storage media at rates of 1 to 1.5 Mbps. However, the code allows bit rates up to 105 Mbps. MPEG 2 was designed for bit rates of 3 to 15 Mbps with a quality up to HDTV (High Definition TV). It also can work at higher rates up to 100 Mbps. The MPEG 1 and MPEG 2 standards are very flexible. It should be possible to improve the performance only by upgrading the encoder. Existing decoder would not require any upgrades to decode the improved signals. The third phase of MPEG is MPEG 4. MPEG 4 mainly describes the compression of very low bit rate audiovisual data. MPEG 4 is not yet available but it is in development. Final tests are planned for November 1996.

D) Audio Compression

Existing audio compression standards (e.g. H.320 video/audio compression or G.728 audio encoding) are mainly designed to transmit human voice. They can not be used for non-voice signals (medical audio signals, e.g. Doppler audio). A European standard of ETSI (European Tele-communications Standards Institute) exists and uses 1.5 Mbps and gives CD quality stereo audio. It was tested for telemedicine purposes and allowed perfect voice communication as well as the transmission of medical audio signals. This European standard will probably be replaced by the MPEG standard that should allow the same function with the same quality or even improved.

4.2.2.4 Relevant Medical Aspects

There are several studies about telemedicine and the above discussed compression codes. The diagnostic accuracy in ultrasonography, histopathology, dermatology and other clinical disciplines is not adversely affected by lossy compression. Compression rates around 10:1 to 20:1 did not change the detection of abnormalities in thoracic X-rays, CT scans or in hand X-rays. However, one study has shown that significant decrease in diagnostic accuracy on screen can happen. For on-line image transfers, it has been shown that transmission behaves best with variable bit rate service. For some medical analysis it may be necessary to use lossless compression.

Still medical images with a depth of 12 to 16 bits can be handled by JPEG. It is possible to switch between lossless and lossy compression in this compression standard. JPEG allows already to deal with the medical requirements. In the future there will be further improvements and therefore even better performances will be possible.

The telecommunication of the DOCC should have the possibility of video conferencing but it is not necessary to do telesurgery. In the MPEG standard it may be that artefacts are built in the decoded video. For video conferencing this is not a major problem. MPEG also has already enough performance for the DOCC project. For telesurgery however, it would be necessary to have a better compression standard.

The discussed compression codes can already deal with a lot of the medical requirements. These promising results show that, in the near future, it will be possible to have diagnosis by telemedicine with the same accuracy as normal diagnosis. Furthermore, space seems not to impose a lot of constraints that the compression codes could not solve.

4.2.3 Data Security and Encryption

The passing of personal information, in this case medical records and data, in electronic format between the DOCC and any distant medical support facility, (for example on Earth), brings forward the issue of data security.

One way of insuring the privacy of communications and data, by preventing unauthorised access, is through data encryption, or scrambling. Commercially available encryption products have reached an advanced state to the point where, in any reasonable time frame, some encryption codes can be considered unbreakable.

This, in itself, raises new problems in that these powerful algorithms can now frustrate lawful government electronic surveillance. In the U.S., this is determined to represent a threat to national security interests and, as a consequence, it is illegal to export some encryption products. There is currently much debate about the balance between the rights of the individual

to use such algorithms and the rights of the government to prevent their use and the flow of data which cannot be deciphered.

4.2.3.1 Currently Used Data Protection Methods

There are several levels of data protection already used in satellite data transmissions. In analogue television, for 'pay-per-view' TV, the synchronisation pulse at the beginning of each piece of data, pertaining to a frame of picture, is removed or corrupted, rendering it impossible for the off-the shelf commercial television set to display the data without further information.

For digital television, a pseudo-random noise (PN) signal is added to the information. The PN signal is a repeated, finite series of zeros and ones generated by hardware consisting of a sequence of n registers, typically of length $(2^n - 1)$ where $n=10$ to 20 . Deciphering of the signal at the receiver is accomplished by a complimentary set of hardware. Statistical analysis of the data can yield the PN sequence, breaking the code, but this may take several days, depending on the length of the sequence, and this data protection method is sufficient to prevent unauthorised access by the general public. This technique also has other uses, for example for breaking up long sequences of zeros or ones in a code which may cause loss of synchronisation in the receiver. It is also the method used by GPS satellites to produce distinct signals from each satellite and for synchronisation.

For military uses, more secure protection is required and in military communications satellites, protection of data is taken a step further into encryption.

4.2.3.2 Key Encryption Systems

Simple encryption systems work by using a single *key* to encode and decode a message. These methods come under names such as secret-key and symmetric cryptography. The key is an instruction detailing how to substitute encrypted code for the original text and similarly, how to reverse the process to obtain the original text from the encrypted code. The instruction can be as simple as substituting one letter of the alphabet for another (an example of a translation table, generally an unsophisticated method and easy to decipher), or can be a complex instruction set developed through the use of number theory.

In single key systems, both the sender of the encrypted message and the receiver of the message carrying out the decryption need access to the same key. This may be made possible by the sending of the key through secure channels before the transmission of the message, but if this single key is discovered, the code is broken.

The generation, storage and transmission of keys is called *key management* and is a major security issue in all cryptosystems. In 1976, the concept of *public-key cryptography* was developed by Whitfield Diffie and Martin Hellman, in order to address this problem.

In this system, each person holds two keys, a *public key* which is published and publicly available, and a *private key* known only to that person owning the key. All communications involve only the public key, the private key is never transmitted or revealed. The message is encrypted using the *public key* of the *receiver*, the decryption can only be done with the *receiver's private key*.

The most widely used public-key cryptosystem in the world, invented in 1977, is called RSA [RSA,1], after the inventors, Rivest, Shamir and Adleman. It is built into computer operating systems, such as Microsoft, Apple, and Sun, is found in telephones, Ethernet cards and is used by many institutions such as the US government, corporations and universities. It is also part of many official world-wide standards, such as ISO9796 (International Standards Organisation), ITU-T X.509, SWIFT (Society for Worldwide Interbank Financial Telecommunications), ETEBAC 5 (the French financial industry's standard) and ANSI X9.31 (the U.S. banking industry standard), and is built into all the major protocols for Internet communications such as S-HTTP, SEPP, S/MIME, STT and PCT. The technology is owned by a Californian firm which means that it is subject to U.S Government export controls.

An example of an electronic privacy program using the RSA algorithm is PGP (Pretty Good Privacy)[PGP] written by Phil Zimmermann and maintained and distributed by Massachusetts Institute of Technology.

4.2.3.3 How it Works

Take two large (e.g. 1024 bit) prime numbers p and q and find their product
 $n=pq$

Select a number $m < n$ which has no common factors with $(p-1)(q-1)$ (except 1)

Select a further number, r , such that $(mr - 1)$ is divisible by $(p-1)(q-1)$.

The public key is the pair of numbers (n,m) , the private key is the pair (n,r)

[<http://world.std.com/~franl/pgp/>]

(It is not legal to export algorithms for encryption from the U.S. with keys of length greater than 512 bits. This is currently under debate in the U.S.)

4.2.3.4 Disadvantages of RSA and New Alternatives

The intense computing power required to perform this method of encryption limits the practical amount of data that can be transmitted using these algorithms (typically several hundreds of thousands of bits processed per second). However a common and quicker method is to use a simple single-key method to encrypt the message, then use the receiver's public-key to encrypt the single-key sending that along with the message. The receiver then uses their private key to recover the single-key from within the message and uses this to decrypt the rest of the original message.

New software such as RKP is being developed which claims a high level of security with processing speeds of up to millions of bits per second which opens up the possibility of using encryption on real-time video.

4.2.3.5 Authentication

The second use for key-based encryption algorithms is in authentication of data. Authentication is used to check that you are talking to who you think you are. For example, person A transmits some unencrypted data to person B requesting that B return the data, encrypted with B's *private* key, which A can then only decrypt using B's *public* key. If the message cannot be decrypted to the original, sent by A, A knows that it was not encrypted with B's private key (and hence possibly not sent by B). This feature can be utilised in data exchange, such as for medical consultations.

4.2.3.6 Conclusions

There certainly already exists mechanisms for ensuring the privacy of transmitted personal medical data and for authentication of the recipient. The most private mechanism (RSA), however, has two disadvantages :

- slow speed and
- political sensitivity.

Depending on the data being sent, either to or from the DOCC, different levels of encryption, or protection may be used, reserving the most computationally intensive and secure methods for the transmission of textual medical discussion, and necessarily using less computationally demanding techniques for high bit-rate data (such as video conferencing) and for access to medical libraries.

4.2.4 Protocols

Many protocols are available at different levels for a space communication. We will focus here on levels above the physical communication link between Earth and the DOCC. This is because we consider the physical link to be part of the mission using the DOCC.

Also the network protocols of today are considered.

4.2.4.1 Earth-DOCC Transmissions: CCSDS Telemetry and Telecommand

The CCSDS is the Consultative Committee for Space Data System, which has been established by member space agencies. The participation in the CCSDS is voluntary, and the results of committee actions are termed 'recommendations' and are not considered as binding by any Agencies. However, several CCSDS recommendations have already been adopted as ISO standards. Several more are Draft International Standards. Therefore, the remote transmissions between the DOCC and ground stations are based on the CCSDS recommendations [CCSDS Document Library].

Packet Telemetry describes the data structures used to transport data from data sources on board a space vehicle to data sinks on the ground. It permits multiple application processes running in on-board sources to create units of data as best suits each data source, and then to permit the on-board data system to transmit these data units over a space-to-ground communication channel in a way that enables the ground system to recover the individual data units with high reliability and provide them to the data sinks (see Figure 4.1).

To perform this action the CCSDS recommendation defines two data structures (Source Packets and Transfer Frames). The Source Packet is a data structure which is generated by an on-board Application Process (e.g. from a medical device or from a data processing software). The Transfer Frame is a structure that provides an envelope for transmitting packetised data over a noisy space-to-ground channel.

Moreover a mechanism called Virtual Channelisation allows to separate sources or destinations with different characteristics (e.g. high/low rate, or real-time/recorded packets). Therefore the proposed system has a good flexibility for possible routing of all types of data streams (Source Packets) to their dedicated applications on the ground [Packet Telemetry CCSDS 102.0-B-4, ISO/DIS 13419].

At a lower level the CCSDS also provides space telemetry channel coding systems to provide cross-support and interoperability among different missions. The system is based on Reed Solomon and convolutional coding [Telemetry Channel Coding, CCSDS 101.0-B-3, ISO 11754].

The communication from the earth station to the DOCC can be accomplished by telecommand protocols which are also defined by CCSDS recommendations [ISO/DIS 12172]. However it may not be adapted for a telemedicine application where we may need strong interactivity and high data rate. Therefore in addition to this (relatively) low data rate telecommand channel, another ground to space channel could be added. This other channel would have an identical format as the CCSDS Packet Telemetry channel. So we would have one high capacity channel in both directions Earth to DOCC, and DOCC to Earth. With this configuration we have high data rate multimedia and interactive communications.

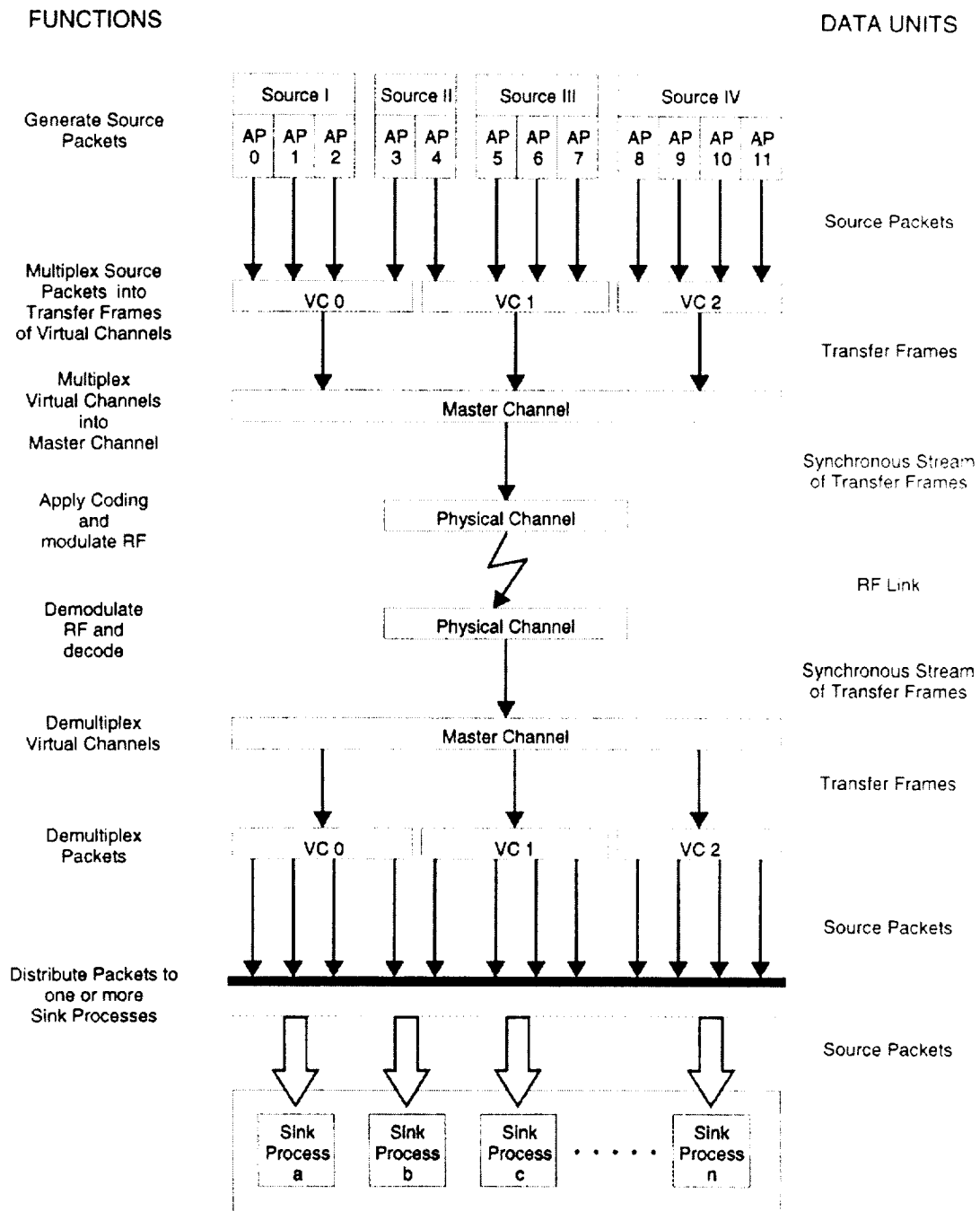


Figure 4.1 Example of Telemetry Data Flow (CCSDS 102.0-B-4)

4.2.4.2 ATM

It is possible to use ATM internet working protocol on top of the CCSDS recommended protocols. This would be an advantage in the real-time and multipoint communications, and it has been already used for telemedicine workstations.

However it may not be indispensable. For point to point, which is the most probable in our case, we can have the communication data directly inserted in the Telemetry stream as Source Packets. If multipoint is needed on Earth, ATM can then be used for further distribution of the information on the ground.

4.2.4.3 Internet

TCP/IP is obviously the most used Internet protocol today, and it is the base of the World Wide Web. It can come easily on top of both ATM and CCSDS telemetry system.

However, because of the limit it has today in terms of bit rate (500 Kbps), TCP/IP will probably be replaced by a sort super-TCP/IP. This will certainly be the protocol to be used then.

The possibility of surfing on the Web might be very important in Earth orbital environment, but on Mars the time delay reduces the relevance of this application. But at the time we are sending DOCC to Mars, the speed of light may not be a limit anymore for communications (never say never ..), and real-time surfing might then be possible on the red planet! Internet will be needed in both scenarios anyway for the use of electronic mail, which can be considered as a psychological support even when you are in good health !

4.2.4.4 Application Level

At this level there has been standardisation efforts towards medical data exchange (IEEE P1157). But a critical issue is the communication between layers, that is to say especially the control of layers between the application level and the networking level (for dynamic bandwidth allocation for instance). Figure 4.2 is a reminder of OSI layers definition:

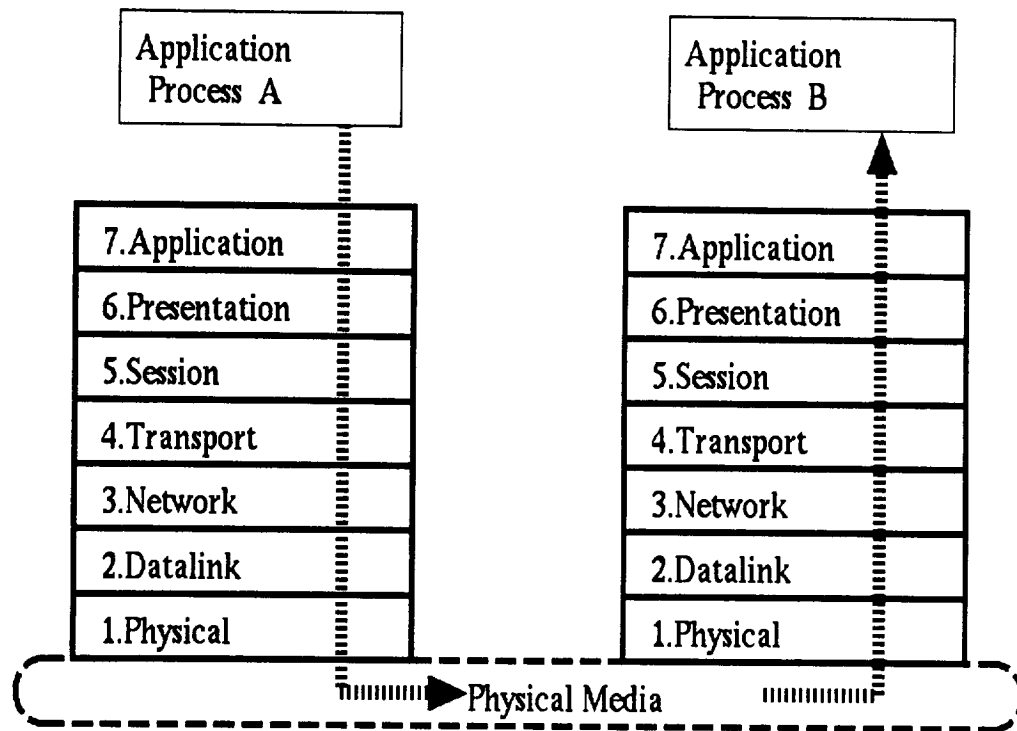


Figure 4.2 OSI layers of definition

4.2.4.5 Serial Bus

In order to interconnect the different peripherals, the **P1394** universal high-speed computer interface standard seems to be an interesting product.

Designed to provide global interconnection, this standard proposed by the Institute of Electrical and Electronic Engineers (IEEE) allows simultaneous transmission of video, audio and data.

Among the significant benefits of this standard are that it eliminates the need for many different types of connectors and cables, so that input/output ports can be integrated, saving board space and reducing the total cost of the computer or system, and it enables data to be transmitted without delay via one cable and one port. Another interesting fact is that the bus configures itself ("plug and play" system), with three main phases to cable configuration: bus initialisation, tree identification, and self identification.

Other characteristics of this serial bus standard:

- extremely low cost
- high speed (100, 200, and 400 Mbps speeds)
- flexible topology
- bus management
- both asynchronous data transfer and isochronous data transfer
- fair arbitration system (allows all nodes equal access to the bus)

- a three layer architecture

and as already told:

- hot pluggable devices with rugged connectors and cables
- self configuring (no need for address switches)

The 1394 architecture is made up of three layers: **the Transaction Layer, the Link Layer and the Physical Layer** (see Figure 4.3).

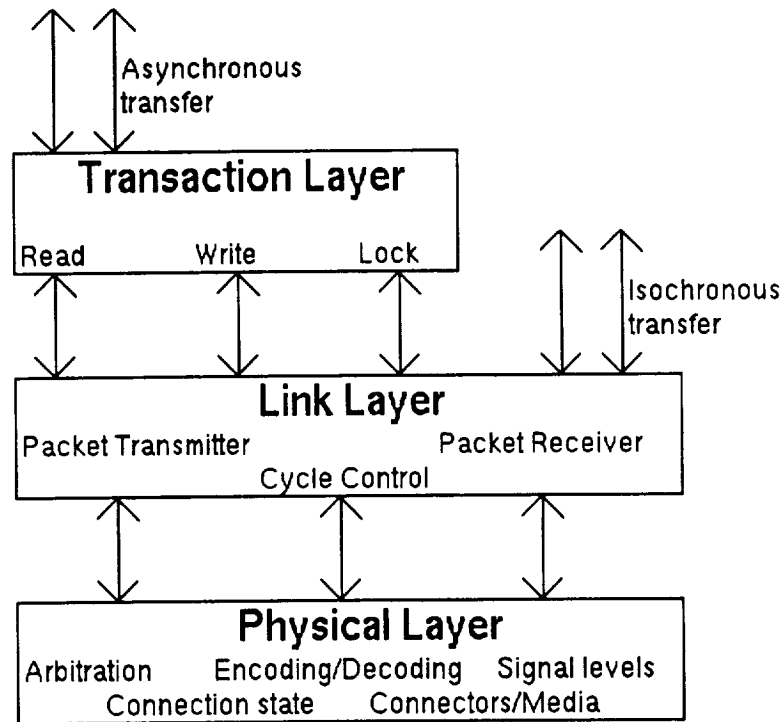


Figure 4.3 The P1394 Architecture

The *Transaction Layer* defines the request-response protocol and has three basic operations: read, write, and lock. A node uses a Write command to request information from another node. The other node responds with a read command. The lock command combines the two other commands.

The *Link Layer* interacts with both the transaction and the physical layers. It is the packet transmitter and receiver and the cycle control. The link layer provides a half duplex data packet delivery service to the transaction layer. It is also responsible for addressing, data checking, and data framing.

The *Physical Layer* translates the logical symbols used by the link layer into electrical signals on the cable. It takes care of arbitration, encoding/decoding, data resynch, connection state, connectors/media, and signal levels.

The **physical topology** for the serial bus is relatively flexible. Up to 63 nodes may be connected with a maximum of 16 hops of no more than 4.5 meters

each between them. Each node can have a number of ports and multiple devices connected to it. Each port has transceivers, terminators, and simple logic. The cable and ports act as bus repeaters between the nodes to stimulate a single logical bus.

The bus uses simple and rugged **cables and connectors**. The cabling is three twisted pairs: two for data and one for power and ground. The connectors are designed to be easy to attach, to lock firmly in place and to withstand frequent connection and disconnection.

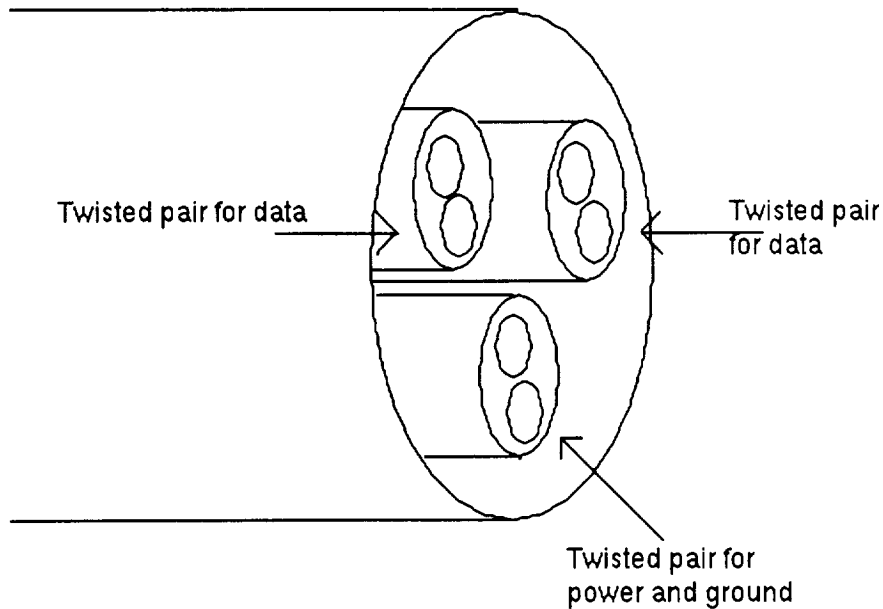


Figure 4.4 Section View of the Cable

Another aspect of the 1394 protocol is **Serial Bus Management**. There are three levels of possible management: *non-managed*, *limited management*, and *fully managed*.

Non Managed: A non-managed bus is capable only of asynchronous data transfer.

Limited Management: A bus with limited management is capable of both asynchronous data transfer and between 8 and 64 channels for isochronous data transfer. It also includes limited power management.

Fully Managed: A fully managed bus is capable of both asynchronous data transfer and 64 channels of isochronous data transfer. It does advanced power management, bus optimisation, topological map, and a speed map.

Asynchronous data transmission is sufficient for nodes that do not require a guaranteed low latency or a precise timing reference. Data like real-time sound or video perform better if such a service is provided. For these applications, the serial bus provides an isochronous access method.

4.2.5 Image Processing

Computational techniques play a vital and ever expanding role in medical imaging related activities. Images of various kinds are increasingly important to medical diagnostic processes and difficult problems are encountered in selecting the most appropriate imaging modalities, acquiring optimal quality images, and processing images to obtain the highest quality information.

In this section, we have a short introduction on the acquisition, display and analysis of medical images. The important aspects regarding the informatic database system which should exist behind any operational image processing system are also covered. The optimisation of these aspects are very important due to all kind of limitations that we can face on a space module when comparing with an equivalent system in an Earth hospital.

Image processing techniques are under continuous development on Earth. The DOCC will include mature and well-proven image processing techniques. Earth state-of-the-art techniques could include, today, image fusion, three-dimensional reconstruction of blood vessels from Magnetic Resonance angiograms, and image-guided radiosurgery. Whether or not in the future the DOCC will include these techniques depends on the level of maturity that a particular technique has reached on Earth and the particular needs of every space mission where the DOCC module will be included.

For the purpose of the core design we will concentrate on the basic image processing techniques and principles behind any DOCC module without going into deep details.

4.2.5.1 Image Acquisition

The first step in a medical image processing system is to obtain the image data. Today, techniques such as X-ray imaging, Computed Tomography (CT) Magnetic Resonance (MR) or just photography can provide useful data for medical diagnosis. In the future new imaging techniques will appear, and the DOCC informatic system should be able to cope with these new sources of information.

The output of this acquisition process should be a number of digital files including annotations which provide information about the image (typically acquisition time, dimensions, comments from the person who acquired the data, etc.) and the image itself which is basically a two-dimensional array of pixels (see Figure 4.5).

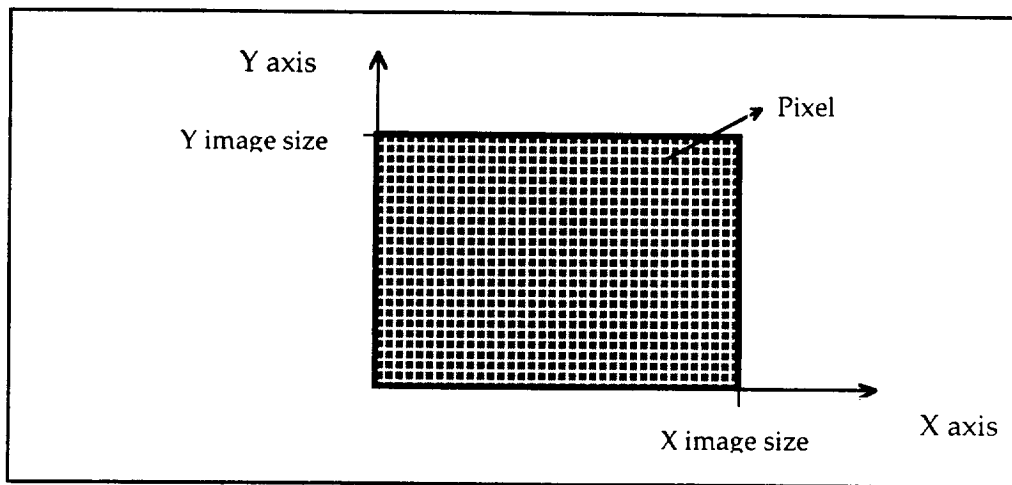


Figure 4.5 Digital image file

Typical medical images can have a dimension of 1024*1024 pixels, with a pixel depth of 16 bits (every pixel requires two bytes of information). For particular applications the size could be increased up to size up to 2000x1500 with a resolution of 24 bits per pixel. The DOCC informatic system will be designed to allow the analysis of these huge files.

The specific point of how these images should be compressed in order to save disk space is covered in the compression chapter which presents several compression algorithms oriented towards image compression.

An important comment should be given here regarding the specific format which should be selected for the image data on the DOCC. Without analysing the different standards which exist today in the image world (GIF, TIFF, JPEG), or more medical specific standards which will appear in the near future, the DOCC module should follow the trends on Earth and adopt the mature standards existing at the time that the particular mission which will include the DOCC module will be designed. In the following years an effort should be done on Earth to agree in an digital image medical standard format valid for the existing medical sources of images and flexible enough to accommodate future sources.

4.2.5.2 Image Display

Once the digital images have been acquired and before deciding how to process a particular set of images, visual analysis helps the medical personnel to understand which operations will allow to take full advantage of the data. An extremely high quality monitor is required in order to allow the visual analysis. The DOCC module will include a true colour monitor (24 bits per pixel).

4.2.5.3 Image Analysis

The next step is to apply specific image processing techniques in order to obtain particular information.

Some examples of the medical images' use can be:

- Image segmentation (e.g. for identifying different tissues)
- Feature extraction and pattern recognition
- Estimation of quantitative parameters
- Analysis of image sequences
- Registration and fusion of data from different modalities (e.g. CT and MR images)
- Generation of anatomical models
- Image reconstruction from underdetermined, multiplexed or noisy projections (considering also the use of prior known information)
- Complex analysis by visualisation of multidimensional data

As mentioned previously, software which allows the development of all these subjects is all the time under development on Earth. Without going into the details, typical software routines should include:

- Software programs to find the maximum and minimum pixels in images and slices, to obtain pixel histograms and do grey-scale or equalised pixel remapping, to extract various sub-images, to resize images, and to generate test images.
- Software programs to clear the whole frame buffer or selected portions of it, to create colour maps, to load and change the window and level of colour maps, to display a colour bar across the bottom of the frame buffer, to "white-out" a range of colour map values, to display whole or partial 3D images as a series of slices with resizing and pixel remapping, to label the frame buffer, to read colour map values and pixel co-ordinates from the screen, and to save the contents of the frame buffer and the colour map.
- Software programs to filter the images in order to reduce the amount of noise in the data, detect contours,...
- Software programs to allow supervised and non-supervised classification of the image data.
- Software programs to allow interactive tracing of Regions Of Interest (ROIs), to resize and translate ROIs, to display ROIs, to generate and display masks generated from the area inside a ROI, and to display total activity counts, means, standard deviations, and other statistics from pixels contained in the intersection of a mask and an image.
- Software programs to create single oblique slices or complete 3D oblique reprojections of images, and to interactively determine the "swing pixel" and planes or angles for these reprojections.

- Software programs to interactively position 3D landmarks on slices of 3D images, to display and edit these landmarks, to do least-squares fits of landmarks from different images and generate 3D warping transform parameters, and to do warping transforms to bring dissimilar images into registration.
- Software example scripts showing the ways in which the different programs can be combined to automate image manipulation tasks and provide useful, quantifiable statistics from images and user interaction. With the current development of extremely powerful Graphical User Interfaces (GUI) we can expect that this particular point will be covered by such GUIs.

This SW could be provided as an evolving CD-ROM, optical disk or even as Earth link file updates for long space missions which would contain a wealth of up-to-date information, software, and source code related to image processing, analysis, manipulation algorithms, file formats and conversion.

The disc should be standard ISO-9660 [ISO-9660] format and can be used on any computer platform with ISO drivers including commercial operative systems and platforms.

We will focus on the use of off-the-shelf equipment in order to reduce costs. The medical software is evolving very quickly and the personnel of every particular mission should use the same SW they are familiar with into the DOCC module.

A special effort should be paid to design an optimised database system which allows to keep large amounts of data in disks and properly use these data with standard PCs with 128 Mbytes of RAM (this is the biggest amount of RAM memory in a commercial PC laptop at the time of writing). For particular applications more powerful machines as laptop SUN machines could be used. The DOCC hardware architecture is prepared to accept the connection of these kind of machines (see Section 4.2.6).

It should be considered the possibility of carrying out some of the analysis/processing (specially if the computational power required is extremely high) on Earth computers. Of course this depends on the nature of every mission. For safety reasons the system should be designed giving to the DOCC the highest level of autonomy, avoiding that a simple communication problem could represent a risk for human life.

The following figure presents a typical informatic database system which will be included in the DOCC (Figure 4.6).

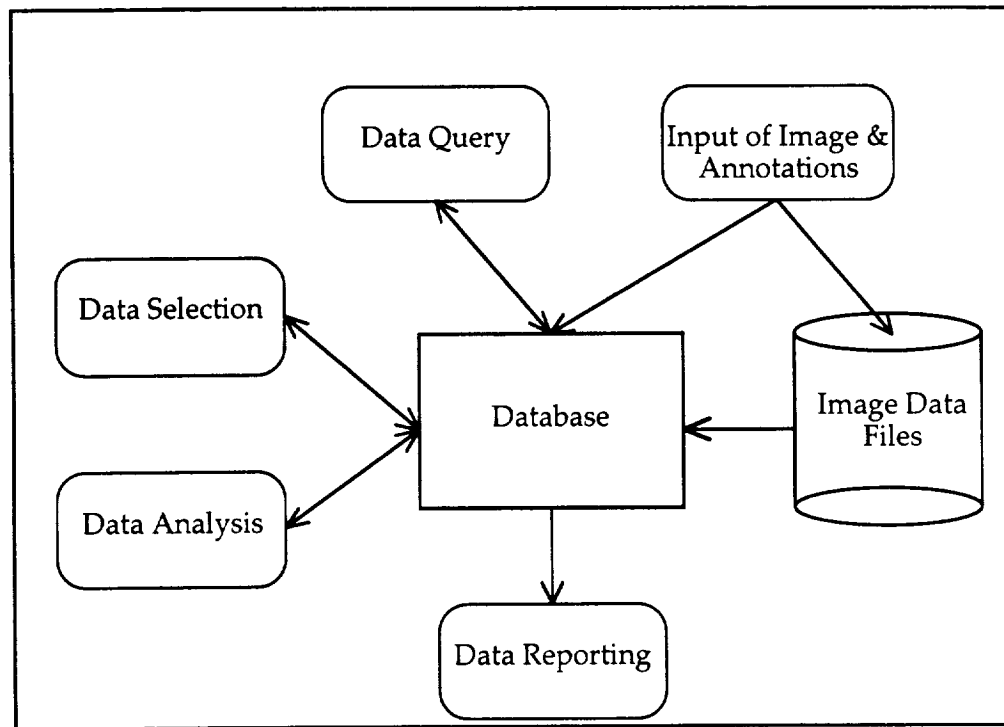


Figure 4.6 Image Processing System Highlighting the Role of the Database

This figure shows how after the ingestion of the image data (and associated annotations into the system) the database becomes the central element of the system. The access to the disk image files is controlled by the database as a result of particular data queries, selections and requests for analysis.

This informatic system will be designed having on mind optimisation of data storage (independently of data compression). Once the full data set (let's say X-ray image) has been ingested into the system the medical personnel can perform some pre-analysis of the data in order to identify "working images" which will be saved on disk as such. Once these sub-images have been saved, together with a quick-look of the image, the whole image can be erased, resulting in an important saving of disk space.

A typical example would be a X-ray image analysis of the head of an astronaut. After ingesting the X-ray image and annotations data into the image processing system, and after some areas of interest ('working images') have been selected in order to erase the full set of data and save some disk space, the medical personnel can query the database for previous data on the same astronaut (X-ray or other sources' data), select the data of interest, analyse the image data and record (both as new database records and new image data resulting from the processing) and generate reports. During this process, if the system identifies that a particular analysis requested has already been carried out (information already present in the database) it will inform the medical personnel and it will show the results corresponding to such analysis.

Another advantage of this kind of system is that external optical disks can be used as storage for the image data files allowing to keep an archive of medical problems classified by patient, kind of image and other relevant parameters. The database itself (which uses small disk space when comparing to the image data files) can be kept on-line allowing to access medical data from the whole mission at any time.

It is easy to find similarities between this kind of informatic system and the Geographical Information System (GIS) well known in the remote sensing field. The generalisation of such a system, including all kind of medical data will generate in the near future the concept of Medical Information System (MIS). The modification of the informatic system presented in order to handle voice, video and any other medical data does not represent important difficulties.

4.2.6 Hardware Configuration and Data Storage

This section has as a main goal to describe, in general terms, the computer and telecommunications hardware needed in order to implement the DOCC. Figure 4.7 presents a diagram of the logical configuration of the DOCC's computer and network systems based on the following assumptions:

- The DOCC is a medical facility that is part of an orbital or interplanetary mission. This mission has its own telecommunications system and the DOCC will use these facilities to provide its ground/space telecommunications.
- The telecommunications and computer hardware of the DOCC must be compliant with international standards such as those defined by the International Telecommunications Union (ITU), Institute of Electrical and Electronic Engineers (IEEE) or other recognised international organisations.
- All the devices which conform the DOCC's communication and computer system must be connected to a common bus architecture using the protocol recommendations defined in Section 4.2.4.
- The hardware devices to be used as part of the computer and telecommunications system of the DOCC must be extensively tested on ground before implemented as part of the DOCC.

DOCC COMPUTER SYSTEM ARCHITECTURE

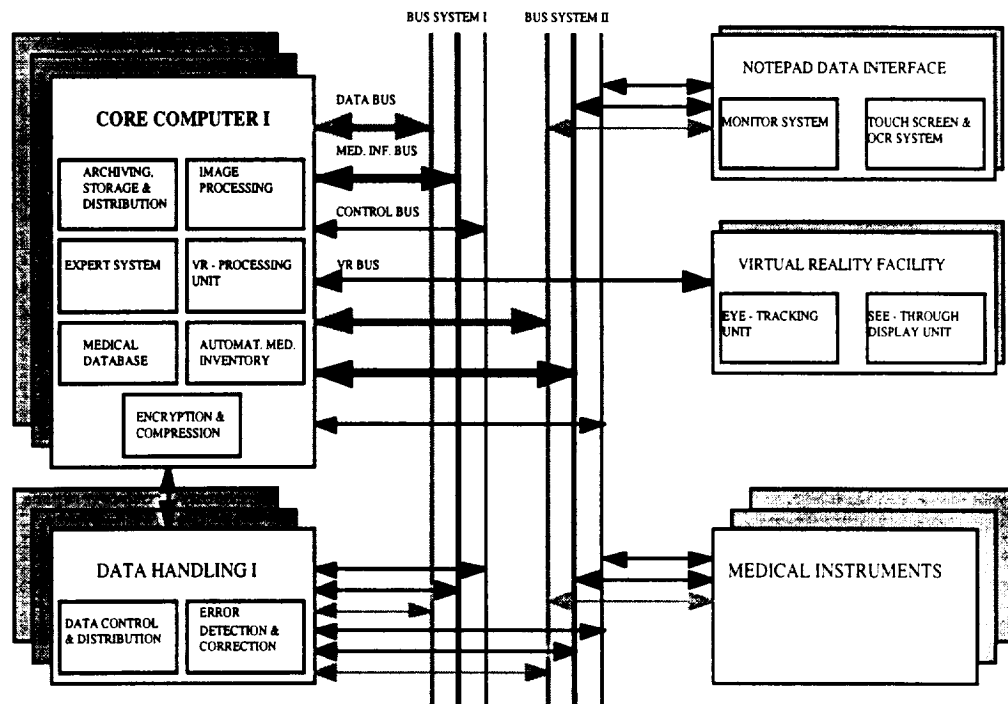


Figure 4.7 Configuration of DOCC's Computer and Network System

4.2.6.1 General Functions and Architecture

The DOCC Computer System consists of the Core Computer, the Notepad Data Interface, the Data Handling Unit, the Virtual Reality Facility and the Bus System Architecture.

The Core Computer has the following main tasks:

- image processing of the medical data
- to support the crew by means of an expert system
- to update the medical inventory
- to support the crew with a medical database and guarantee an automatic update
- to generate the virtual reality data in real-time
- to archive, store, and distribute the medical data and guarantee a quick access
- to encrypt and compress the data

All of the above mentioned Computer Systems communicate via a Bus System which is divided in:

- Data Bus
- Medical Information Bus
- Control Bus
- Virtual Reality Bus

To assure a quick data access of the medical instruments the Bus is divided into the Medical Information Bus and the general Data Bus. The Control Bus provides the infrastructure to command and control the DOCC Computer System. To achieve the high data throughput which is required by the Virtual Reality Facility there is an own VR Bus which is able to transfer the VR Data without any delay.

Because of the complexity of the DOCC System the failure tolerance of the complete system is of extreme importance. Each of the computer systems exists several times and works in parallel to process the same data. After the data is processed a mutual verification of the results takes place. If there are any differences between the results, an algorithm is started to point out the system that is responsible for the error.

4.2.6.2 Communications Media

In a telecommunications system, it is fundamental to define the type of physical communications media to be used. In the case of the DOCC's component connections, high reliability is a key issue. Shielded copper cabling would be sufficient in the case of P1394 protocols. It is also possible to consider fiber optic cabling as a second alternative.

In both cases, the appropriate terminal interfaces are required and the upper level protocols used must provide information to select the optimal communications media for the system.

Since the DOCC's space to Earth communications are relying on an orbital or interplanetary mission, the communications media to be used from Earth to space depends on the specifications of this mission. From the DOCC's point of view, a highly reliable, thoroughly tested transmission media is required. The use of radio frequency technology can be said to comply with these requirements.

Optical space communications could be a possible alternative, as well, but further investigations and testing must be done before considering it as a feasible option. The present development in this field does not provide a highly reliable media when exposed to the noise present in the Earth's atmosphere.

4.2.6.3 Computer-to-Network Interfaces

It is necessary to have the appropriate and compatible telecommunications interfaces between the medical equipment and the main telecommunications

system of the DOCC. These interfaces must be compliant with standards defined by international organisations such as the ITU, IEEE or others.

The computer-to-network interfaces in a telecommunications system are responsible for controlling the flow of data between the *data circuit terminating equipment* (DCE) and *data terminating equipment* (DTE), making sure that the DCE has sufficient instructions to deliver the data correctly. It also allows the DCE to prepare the distant DTE and confirm receipt of data if necessary. The physical configuration of the interfaces to be used for the DOCC will depend on the communications protocols used.

The interface itself is designed either for 'parallel data transmission' or 'serial data transmission', the latter being the more common. Serial transmission requires only one transmission circuit, and so is far more cost effective for data transmission on long links between computers. The parallel data on the computer's bus is converted into a serial format simply by 'reading' each line of the bus in turn.

The interface performs the following basic functions:

- Clocking and synchronising the data transfer
- Regulating the bit rate, so that the receiving device does not become swamped with data
- Providing a common electrical Earth (or 'ground') between the devices

Some of the possible computer-to-network interfaces that could be used are RS232C, V.35 and IEEE 1394.

4.2.6.4 Peripherals

In referring to the DOCC's hardware configuration, the peripherals are the medical devices that are attached to the network and controlled from a central point. These peripheral devices must have the appropriate interfaces in order to guarantee the networks appropriate operation.

The telemetry and command control of these devices will be done from the Notepad Data Interface presented in Figure 4.7.

4.2.6.5 Processing Capabilities

A high-performance UltraSPARC multiprocessor system is used to fulfil the DOCC requirements. Short latency to main memory and shared data, high data bandwidth, and flexibility in the coherency protocol are the main characteristics. This level of system bandwidth allows fast transactions between the processor and the main memory system besides efficient interprocessor communication through direct processor-to-processor messaging capability. Optimal performance for advanced multimedia

applications such as videoconferencing, 2-D, 3-D imaging, animation and virtual reality is promoted.

- Performance
 - Scalable performance ranges up to 500 SPECfp92
 - Processor's clock rate ranges up to 200 MHz
- Power consumption
 - less than 20 milliwatts in the EPA Energy Star compliant mode
- Operating System Support
 - is given for all UNIX-Derivates
- Multimedia Support
 - 30 frames per second, transmission rate from main memory to frame buffer: 300MB/s

Another big advantage of the SPARC-architecture is, having full external cache support on the chip. This eliminates the need for glue logic, allowing the processor to directly interface with the SRAMs that make up external cache memory. In the same way, UltraSPARC's ability to execute graphics operations internally can eliminate the need for expensive graphics circuitry, like a dedicated video processor.

4.2.6.6 Data Handling Subsystem

The Data handling subsystem has the task to (1) control the data flow on the Bus System, (2) detect errors, and (3) correct errors. If any error is detected, a failure recognition algorithm is executed to find the error and try to start a repair procedure.

Within this section a general data flow diagram for the DOCC computer system will be presented. Figure 4.8 presents this flow, indicating the major components of the computer system architecture and the data flow between these components.

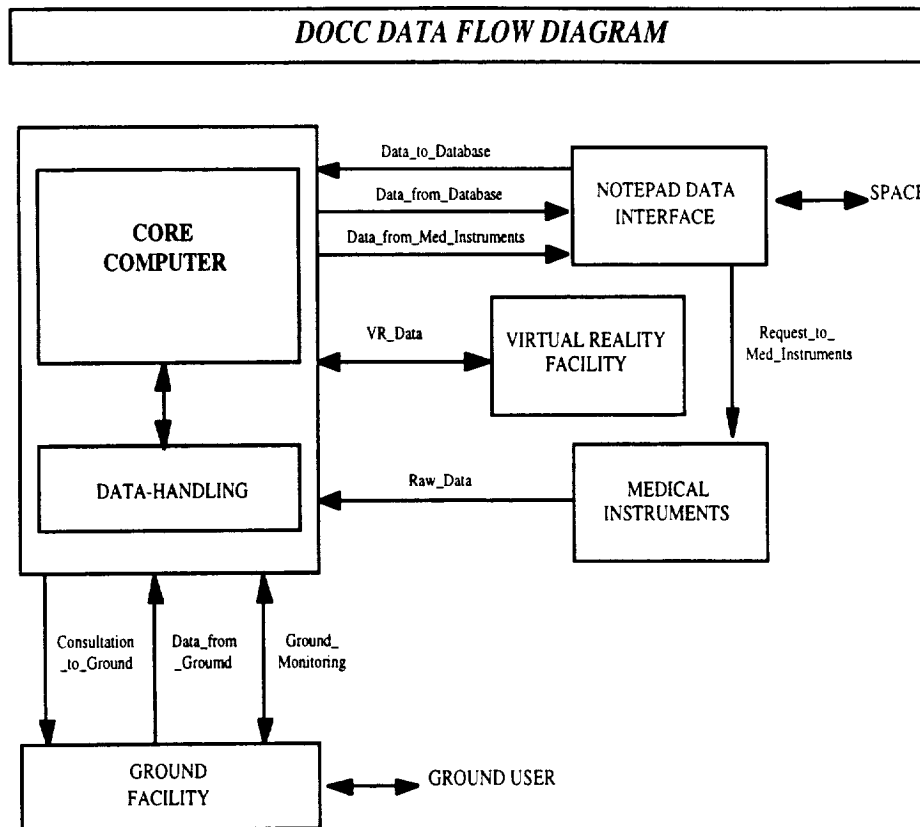


Figure 4.8 Data flow within DOCC's information system

The database system of the DOCC will be composed of four main types of information:

- inventory control
- patient records
- electronic medical literature for consultation
- knowledge base of medical information

The *ground user* of the system is a medical specialist or a member of the DOCC team in the ground facilities. The *space user* is a crew member who uses the system in space.

The following table describes the data types according to the name given to them in Figure 4.8.

Data Type	Description
Data to Database	• A request to consult or modify data from the database system • Data updated or modified in the database system
Data from Database	• Data retrieved from the database system
Request to Med Instruments	• A command sent to the medical instruments

Data Type	Description
Data from Med Instruments	Data sent from the medical instruments and processed in the Core Computer System before reaching the space user
VR Data	Virtual reality data exchanged between the processing unit and the virtual reality facility
Raw Data	Unprocessed data (e.g. images) coming from the medical instruments
Consultation to Ground	- Consultation from space to medical specialist on ground - Consultation to medical database system located on ground
Data from Ground	- Data coming from ground support team - Data retrieved from ground database systems
Ground Monitoring	Data flow between ground and space related to monitoring and eventual remote control of the DOCC

Table 4.11 Different Data Types

4.2.6.7 Storage Devices

Storage devices are electro-mechanical contrivances that physically inscribe data onto recording media such as magnetic disk, magnetic tape, CD-ROM, or optical disk, then read it back later. Because of the different mission scenarios the whole backup system is designed modular and can easily be adapted to the special needs. The DOCC on board storage components are divided into three subsystems

- on-line storage for the most important data sets
- off-line storage for archives, backup system security
- hybrid near-line technology for quick external data access

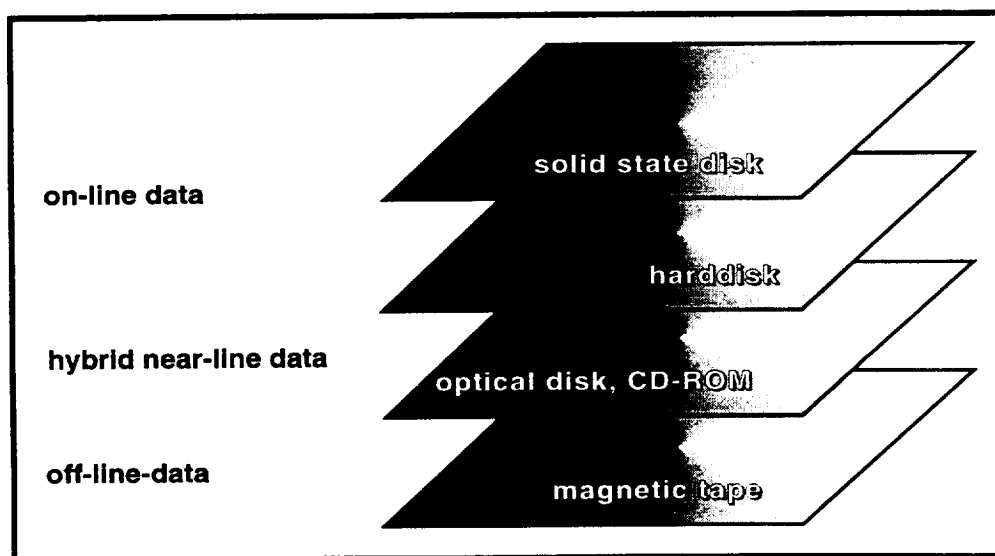


Figure 4.9 The Structure of the DOCC On Board Storage Components

The storage devices provide the highest level of data availability, accessibility, reliability and performance. They are easy to configure and to manage over time. Automatic security backups are performed once per day, updating only used files. Operating System and Software are stored on tape and CD-ROM easy to install, in case of a non-recoverable system crash. An UPS (Uninterruptable Power Supply) device guarantees a proper shutdown in case of power loss. The storage devices are connected via the high-bandwidth and highly functional SCSI-standard, which suits just about every kind of system and storage.

Table 4.12 gives a short overview on performance and capacity of the storage devices. Please consider that these figures nearly change from one day to the other.

	STORAGE CAPACITY	TRANSFER RATE
RAID	6 GB - 1 TB	33 MB/s
OPTICAL DISC	1.3 GB	r/w 0.8/1.6 MB/s
CD-ROM	681 MB	r/w 615 KB/s
MAGNETIC TAPE	40 GB	6 MB/s

Table 4.12 Performance and Capacity of Storage Devices

RAID (Redundant Arrays of Independent Disks) allow uninterrupted access to information through redundant, hot swappable hardware components. In addition to rugged disk and tape modules, the system can be configured with, dual controllers, dual redundant load sharing power supplies, dual main power inputs with cable lock guards and up to three cooling fan modules. Through the rack-mount configuration the RAID can easily be serviced via front panel access. Hot-swap, hot-spare drives enable on-line replacement of a failed drive.

At the moment, developments for **Solid-State Data Storage** for space systems are on the way offering unmatched performance, which is extremely interesting for a Mars mission storage scenario. This extremely large RAM subsystems for high-speed, high-volume data handling applications offer new possibilities in visualisation and scientific applications. An entire compressed video is stored on a single board, an instant playback up to 1920 x 1080 pixels possible (24 frames per second i.e. the memory speed is over 1 GB/s), high speed file access for compositing, rotoscoping, image processing, rendering and digital paintings provided.

Solid-State Disk:

- Single unit expandable to 26 GB
- Units cascable for unlimited capacity
- Simultaneous read and write up to 200 MB/s to different blocks of data

- Hundreds of times faster access than disk drives
- Optional single-bit error correction with double detection
- RAM Capacity:
 - 128 MB - 6.5 GB (4M DRAMS) in 128 MB increments
 - 512 MB - 26 GB (16M DRAMS) in 512 MB increments

For the use in space the system has to be very reliable. In terms of size and technology the key attributes are: compact, affordable, lightweight, fault tolerant, robust and scalable. Mechanisms in order to tolerate faults occurring in the storage medium as well as in the rest of the electronics that control the storage portion should be implemented and an efficient radiation shielding provided.

Research works are on the way to develop an innovative material that can be used in space especially for the shielding of microelectronic parts . During application the adhesive component will be fluid so that a precise and localised shielding of the sensitive components is possible. After solidification the material forms a permanent adherent radiation barrier with minimal weight on the microcircuits will be radiation hardened

4.2.6.8 Notepad Data Interface

The Notepad Data Interface consists of a DIN-A4 size active matrix TFT display, its own processor system, I/O ports, a touch screen, and a battery pack.

Following tasks can be done with the NDI:

- monitoring medical data
- typing in data by means of a keyboard or a pen system with a character recognition software
- stand alone work at least for 2 hours

The idea of this system is to provide a powerful hand held computer system which is able to monitor graphical data with a high resolution and a high colour depth to meet the medical requirements.

There are two possible ways to enter data into the system. The first is to use a notebook size keyboard which has to be connected to the NDI. The second is to write with a pen directly on the display which has an automatic character recognition software.

It is possible to fit the NDI in the docking station which has a build in power supply to charge the battery pack. Furthermore the network adapter is in the docking station to connect the NDI to the bus system.

After loading the software the NDI can be removed out of the dockingstation and it is possible to work for at least 2 hours.

4.2.6.9 Virtual Reality Facility

The Virtual Reality Facility (VRF) is a very powerful system to provide opportunities to do exercise, medical training, surgical practice, mission training, and similar activities. The system consists of the VR-Processing Unit and the Head Mounted Display and is connected together through the Virtual Reality Bus infrastructure.

To achieve the required data rate for the real-time application the VR-Processing Unit has as core a high-speed three dimensional graphics rendering chipset.

A very high effort was made to design the Head Mounted Display which offers the eye-tracking function as well as a see-through option.

In many applications it is necessary to have the information were the person is looking to. This data is measured with the two dimensional eye-tracking system and fed back to the processing unit to calculate the new VR image.

The see-through option makes it possible to combine the reality with the virtuality via a special non linear optical device. It is also possible to use the system only as VR-Display. Two high resolution 3 cm diagonal MIM active matrix LCD displays generate the original picture. A special optical mirror system put the images to the optical element which combines now the reality with the virtual pictures.

4.2.7 Ground Segment Requirements

For security, upgrade and problem solving reasons, we suggest that the hard- and software configuration for the DOCC computer system on earth should be the same as used in space. This terrestrial system provides an optimal testing environment of new components - either hard- or software - before they are built in or installed in the space facility.

4.3 ARCHITECTURAL DESIGN

Historically, the function of the architect has long been the development of forms which meet a set of requirements. Behind this rather bland description, there lies a twenty-five century-old art. The architect must combine the bare functions demanded by the client into a space in which people can carry out any tasks required of them in the most convenient fashion possible. It is not enough to lump things together; defining their spatial relationship to each other and to the people who use them and live with them is the job of the architect.

In the case of a medical facility, these considerations of spatial relation are especially important. Design should be clean and uncluttered; the time taken to fumble for instruments can be the time it takes someone to die. In space, the constraints on functional and aesthetic design are even greater. There is no way to step outside for some fresh air and a cigarette. The module is a small volume contained in a restrictively shaped geometry. In this section, a design process is outlined which attempts to take account of these constraints.

4.3.1 The Functional Requirements

A medical facility is not an oversized metal coffin. It must be of a form which people can work in. It is also not a thing. It is a *space* in which functions are performed by people who must occupy the area. This said, we start from function and allow form to follow. Form will be adapted to function, as the module geometry allows, rather than forces, function to fit some arbitrarily defined shape.

The functions to be carried out in the medical facility can be divided into three basic families according to their gravity or, equivalently, to their probability. The first is the group of emergency procedures, which may involve surgery or other serious interventions. These are rare but equipment and space must be available for them to be carried out immediately. The second family is of those things which can wait—headaches, sore throats, minor cuts. Here, waiting five minutes may be inconvenient but is not dangerous. These functions are comparatively common although there is no way to know exactly when they will happen. The third family is of the things that are guaranteed to happen, the countermeasures. These take up to three hours a day of each crew member's time. For a large crew, this means that a large space is required simply to hold exercise equipment. The challenge to the architect is to devise a space where these functions can be integrated without being so closely integrated that there is no room to move.

In this section, a set of racks containing medical equipment and other facilities are described. These *are not* the DOCC. The DOCC is the set of units installed in a space where people can work and live making use of the resources provided as they need to. In chapters 7 and 8, the use of the DOCC is described by showing how it can be adapted to two missions.

The important issue is that of flexibility. If the core module is properly designed it will be possible to use it in almost any mission with very little change. Some equipment may have to be added to tailor it to a given mission but this is part of the adaptation process. The important feature is that the core module should not need to be changed for a mission.

4.3.2 Layout And Use Of Volume

The core module is made up of a set of racks which provide the basic functions required for any space medical facility. These functions include instruments for medical procedures, a bed/chair unit, supplies of

pharmaceuticals, countermeasures' equipment, and miscellaneous lighting, display and computer units. In total, the core equipment for a crew of three people has a volume of about four cubic metres requiring three standard racks. This does not include the storage space required for pharmaceuticals and other supplies. The space needed for these will depend on the mission, so we assume that one more rack will be needed. It should be noted that more racks will be needed for a larger crew but the number required will not scale linearly. A crew of six will not necessarily need eight racks as much of the equipment carried can be used in turn (e.g. the astronauts may use the countermeasures devices one after another) or is not meant to be used for every crew member (the emergency equipment for example).

One possible basic rack is shown in Figure 4.10. This contains a standard set of medical equipment as shown in Figure 4.11.

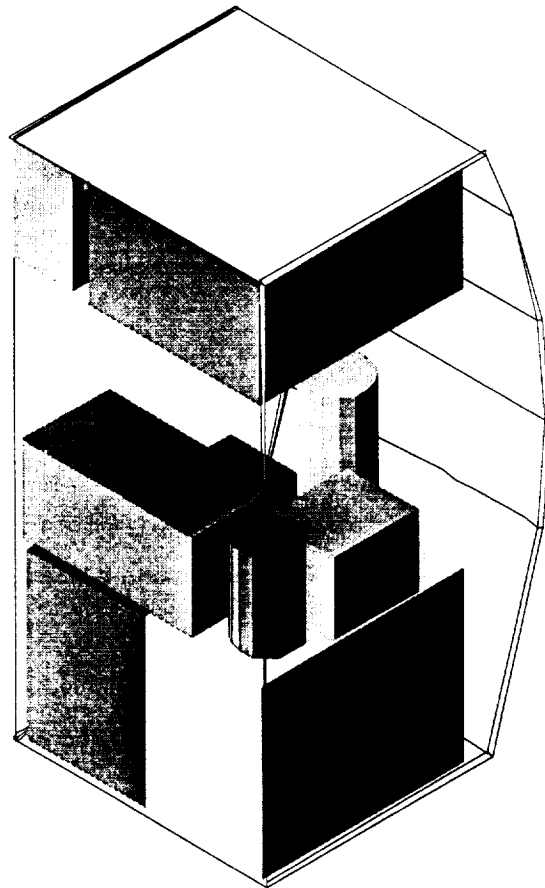


Figure 4.10 The Arrangement of the Core Rack

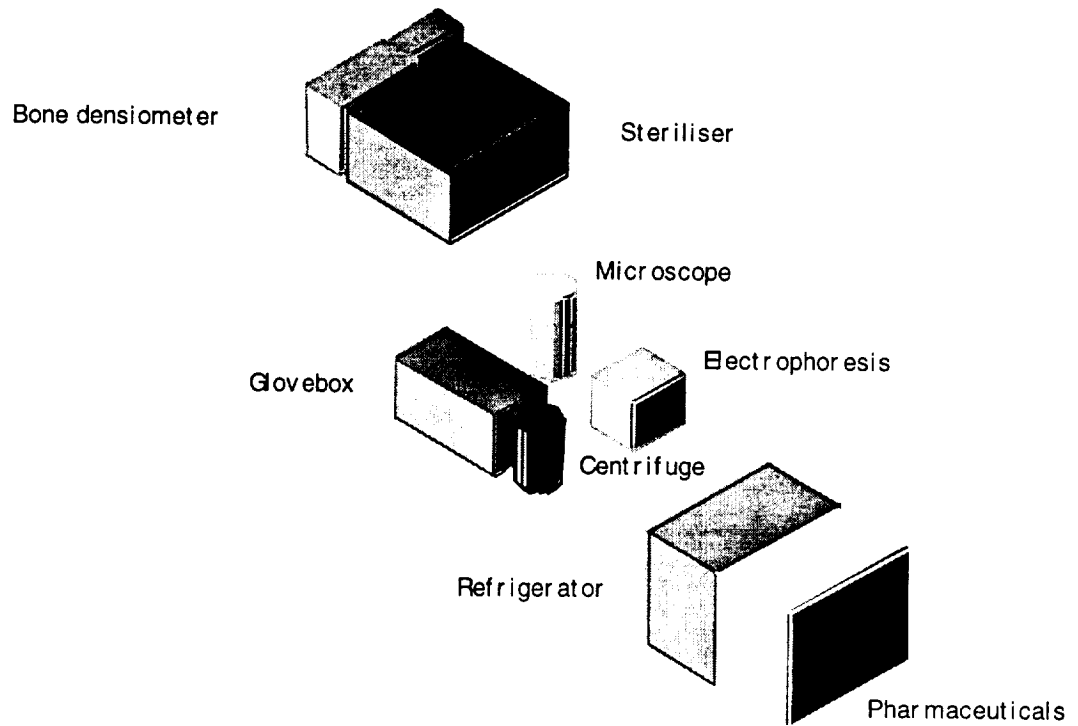


Figure 4.11 An Exploded View of the Core Rack Showing the Arrangement of Equipment

The equipment shown in block form in Figure 4.11 is based on dimensions supplied by the medical requirements and demonstrates how hardware can be fitted into a rack in a space efficient manner.

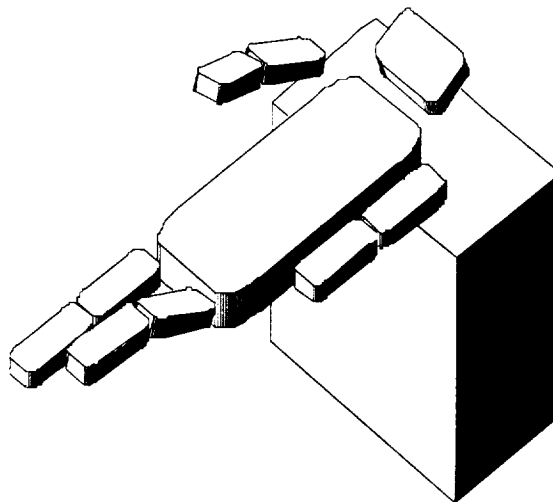
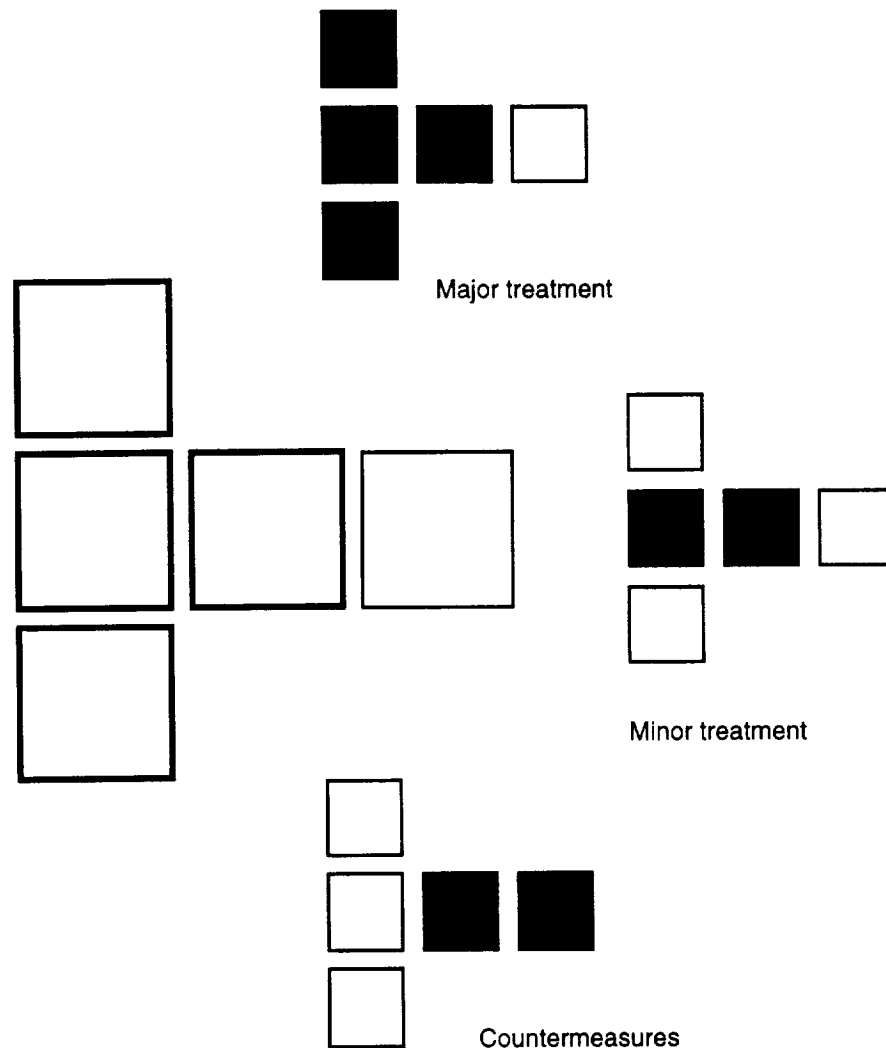


Figure 4.12 The Bed

The bed shown in Figure 4.12 is described in more detail in Section 4.3.4 where some of its important features are described.

As noted above, the layout of the DOCC is also important. Figure 4.13 shows how the families of functions might be arranged in a module based on the Italian Mini Pressurised Logistics Module [Boeing, 1995].



NOTE: Racks are Printed Bold in the Main Diagram

Figure 4.13 The Use of Core Module Space

In this figure, the three families of functions are arranged linearly along the module, with some overlap between the space taken by each one.

4.3.3 Virtual Reality Facility

The Virtual Reality Facility, or VRF, is a multi-purpose space located adjacent to the DOCC in the core design. It is located proximal to the DOCC because the VRF will often share monitoring equipment and other medical equipment with the DOCC when the VRF is used for exercise countermeasures and when it is used for medical evaluation or training. The VRF may be physically isolated from the DOCC, however, when the DOCC is being sterilised for surgery. Its primary purpose is to support the medical facility, although it is expected that it will be in use most frequently for

secondary non-time-sensitive activities. On a conceptual level, the VRF provides temporary simulated access to environments and resources back on Earth during a space mission. This resource becomes more essential, therefore, in missions which travel farther from Earth and in missions of longer duration. The VRF will be located adjacent to the DOCC so that imaging computing resources may be shared, so that the physiological and neurological condition of users may be monitored electronically from equipment in the DOCC, and so that users may conduct medical training using equipment in the DOCC. The VRF will serve some or all of the following purposes, depending on the exact scenario in which it is implemented:

- Exercise
- Medical Training
- Surgical Practice
- Mission Training
- Psychological Therapy
- Psychological Testing
- Ground Operations Simulation/Training
- Private Video Communications
- Private Space for Crew Members
- Entertainment

The VRF is supported by a dedicated high-speed three dimensional graphics rendering chipset. This chipset would be integrated into the central computer of the larger facility in most mission scenarios in which the DOCC will never be moved physically out of the larger vehicle. VR face goggles and body suits for a minimum of two crew members are stored in the core VRF, and more may be required for certain mission scenarios or if crew members vary widely in body size. The floor of the VRF, when in use, is a treadmill which reacts to pressure by crew feet in a particular direction with equal motion in the opposite direction. Therefore, while it is not possible to change one's physical location on the VRF floor while it is active, users have the sensation of motion in any direction. This physical sensation is complemented by the visual illusion of motion produced by the goggles whenever the treadmill is moved. Additional athletic equipment for actual muscle exercise during VR sessions will also be included.

The technology in the VRF may represent significant development expense. However, it is also one of the best candidates for commercial spin-offs, especially in entertainment, and the entertainment industry may independently develop the requisite technologies prior to the development of the DOCC. The VRF will also occupy one of the largest spaces within the crew living area under most mission scenarios. However, the ability of this single space to serve as private space for each crew member represents a significant space saving over most alternative vehicle designs, especially in long-duration

mission scenarios, in which a private space for each crew member is typically deemed necessary for maintaining psychological health.

4.3.4 Some Details

It is neither the intention nor the purpose of this section to produce a detailed design of the medical facility but an explanation of some aspects of the equipment is in order.

The bed has been designed to be flexible. It will need to be used as a table for surgery, a chair for dentistry and, possibly, as a bed for extended recovery and recuperation. Operations are difficult if the patient is floating away so restraining straps are provided for use in microgravity. See Figures 4.14 and 4.15 for an idea of how it might look.

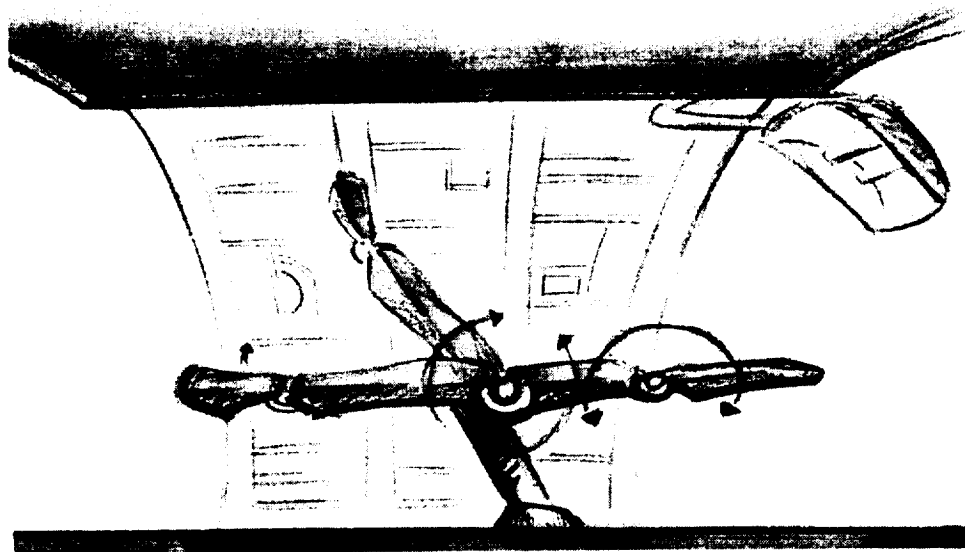


Figure 4.14 A Concept of the Bed

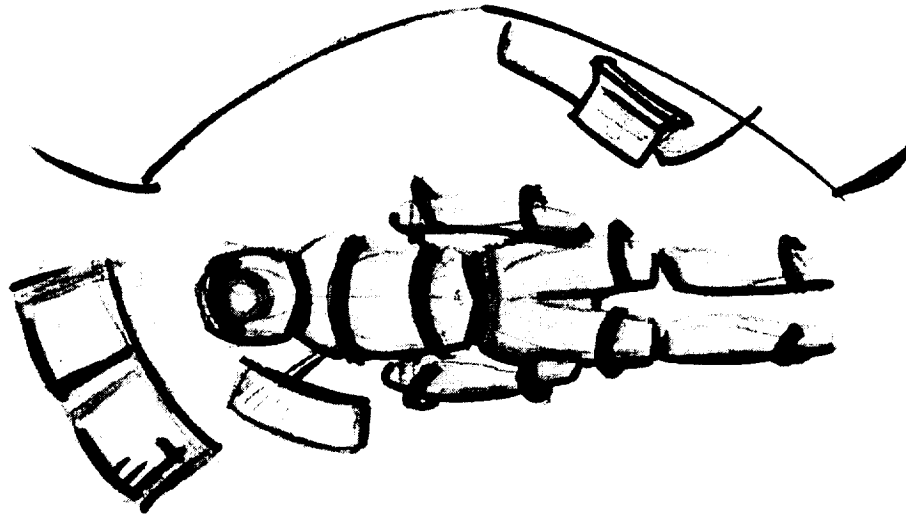


Figure 4.15 The Bed from Above

In 'surgical mode' the bed functions both as a conventional operating table and as a support for the patient. The articulated arms, leg and head sections allow the bed to be used as a splint when a patient's limbs must be fixed, for example in the case of a broken bone. This also ensures that a patient can be held in the position most convenient for a surgeon when an operation must be conducted. Equipment such as respirators goes in a rack under the head support, as shown in Figure 4.12. For imaging, an X-ray imaging unit built into the torso section is used with a hand-held X-ray source for examinations.

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TRW Ramcube ATM Stream Generator, <http://www.trw.com/ramcube/whatsnew/>

TRW Ramcube Memory Board, <http://www.trw.com/ramcube/products/rcbrd/>

TRW Ramcube 26G, <http://www.trw.com/ramcube/products/rc26g/>

CCSDS/ISO standards:

CCSDS 102.0-B-4, ISO/DIS 13419 "Packet Telemetry"

CCSDS 101.0-B-3, ISO 11754 "Telemetry Channel Coding"

ISO9660: ISO standards may be purchased from a country's national standards body. In the USA, this is ANSI, in the UK it is BSI (British Standards Institute in London), in Switzerland, SNV (in Zurich), DIN in Germany, AFNOR in France, JSA in Japan, etc

Chapter 5

Ground Segment

This chapter will detail the medical requirement considerations for providing ground support for the designed DOCC space segment, as described in Chapter 4. It will also provide a functional description of the Ground Control Centre (GCC) which will work in conjunction with the DOCC space segment in an effort to maintain human health and performance in space.

5.1 GROUND SEGMENT MEDICAL REQUIREMENTS

This section describes the ground support necessary for the Distant Operational Care Centre (DOCC) from the perspective of the medical requirements. Particular focus is placed on aiding the trouble shooting process concerning soft- and hardware problems, as well as emergency support in case of medical problems including surgery.

5.1.1 Computerised Health Maintenance System

In the ground segment the CHMS will include:

- mirror system of the in-flight software and hardware on the ground which will aid in trouble shooting and function as a backup facility;
- communication network to correspond with specialists on the ground.

The CHMS will have a system that is exactly the same as the in-flight system as part of its ground segment. This “mirror-image” system is required for several reasons:

- **Software integration testing and debugging:** New information and errors in the knowledge base and software will be discovered even after stringent testing procedures. Therefore, a method is needed to test the system before it is put into space.
- **Hardware testing:** In the event that the space system is not functioning normally, a ground system will be used to help emulate the errors that are occurring and help delineate which hardware component has failed. In addition, several software routines will be written which will be capable of self-diagnosing hardware problems.
- **Human Factors:** The ground segment will be working with the same medical environment as the crew, which will facilitate the communications and procedures between these two segments.
- **Backup purposes:** The system must have a backup site, in order to ensure data retention and functional performance.

The CHMS will also contain a communication network made of specialists from many fields, as described in Section 5.2.1. These specialists will be called upon to help solve medical problems as they arise. Communication between specialists will use existing telecommunication technology. In addition, not all medical information will be available to each specialist. For example, a dermatologist may not need to know information regarding psychological problems.

The ground segment will also contain archival sites to store data that is not needed on-line.

5.1.2 Surgery

5.1.2.1 Human Interface

A General Surgeon should continuously be available and working in three shifts so it will be possible to handle emergencies. In addition, a team of surgical sub-specialties (brain, vascular, plastic, maxillae-facial, cardio-thoracic) should continuously be available as consultants, in a 24 hour on-call basis. There should be a link to a major hospital near the landing site to deal with evacuated patients in an emergency basis.

5.1.2.2 Hardware

When in an orbital station, and if the mission does not allow a surgeon in the crew, a Robotic Surgical Assistant (RSA) teleoperated from the ground station should be used. The operation will be performed by the ground based surgeon on duty or, when necessary, by an on-call specialist requested for a precise surgical operation, to deal with the surgical and trauma problems that may arise among the crew.

A very good system has already been developed by SRI International [Bowersox 1995, Green 1995]. It is composed of a Console Unit (CU) and a Remote Slave Unit (RSU).

- The CU should allow the operator to effectively project natural skills and dexterity into remote or hazardous environments. The system is composed of force-reflecting control manipulators, stereoscopic (3D) view of remote site, stereo sound, voice control, foot switches and other control and display devices. The arrangement of manipulators and 3D view produces highly effective telepresence.
- The RSU should have tools mounted on the slave manipulators, and instantly and precisely follow the operator's hand motions. The over-all system features are: force-reflecting slave manipulators, high-resolution stereo cameras for 3D viewing, stereo microphones for sound localisation, and interchangeable tools.

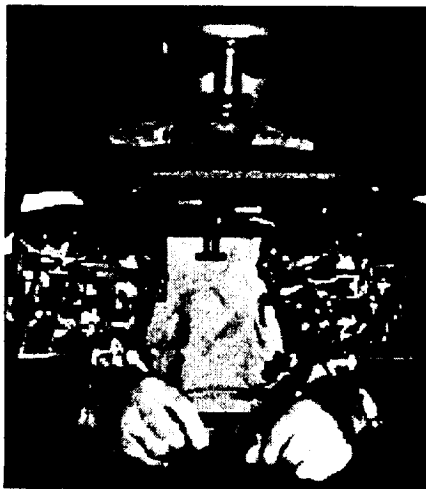


Figure 5.1 Operator with the Handles and a view of the slave unit working in the surgical field (SRI International)

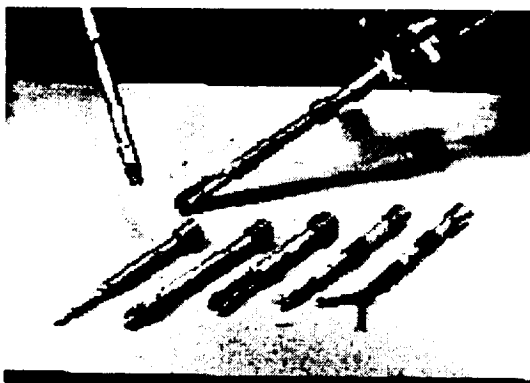


Figure 5.2 Interchangeable tools (SRI International)

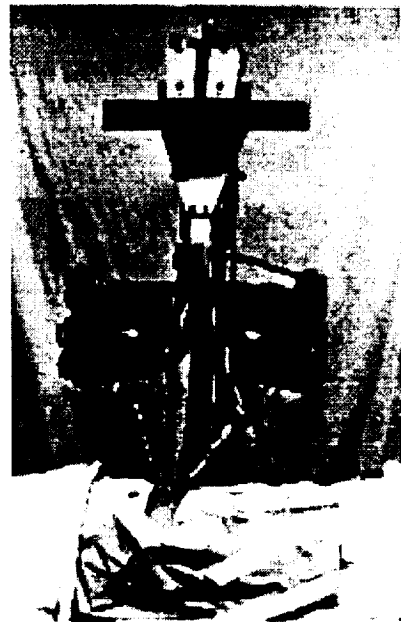


Figure 5.3 Console Unit and Remote Slave Unit (SRI International)



Figure 5.4 Surgical Robot operating on a patient "Dummy"

5.2 GROUND OPERATIONS SUPPORT

This section describes the ground operations support for the DOCC. The ideas described here are generic recommendations for how the ground management of a remote medical facility might be performed.

The DOCC ground operations will be managed and controlled from a central Ground Control Centre (GCC). This DOCC GCC will be the central management centre covering all training, maintenance, upkeep, and day-to-day operation of all DOCC facilities. The GCC ideally will be able to oversee the operation of several remote facilities simultaneously. Figure 5.5, below, depicts the interactions between the GCC, the DOCC in space, and the people and resources located on the ground.

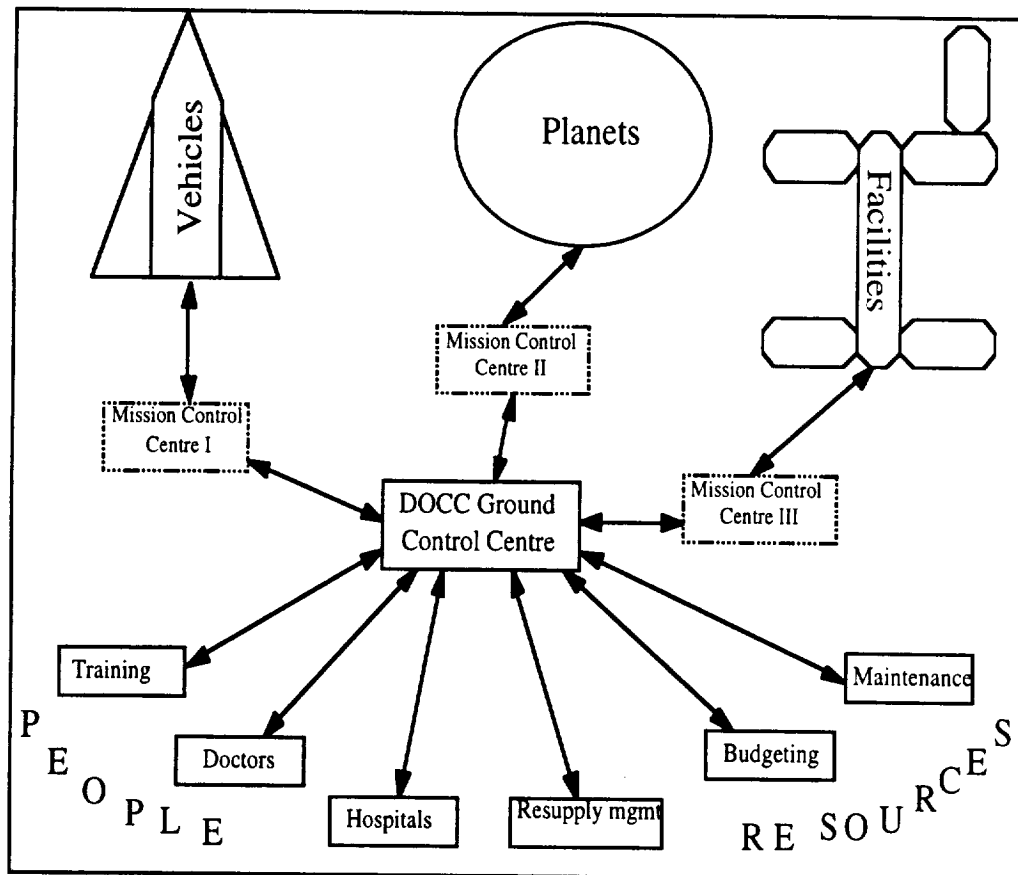


Figure 5.5 GCC Interactions with Space and Ground Resources

5.2.1 DOCC GCC Functions

- *The day-to-day operations of the GCC will focus on 24-hour monitoring of the remote medical facilities.*

This constant monitoring will provide the remote facility with all the necessary ground support functions. Ideally, a flight surgeon will always be on console to provide continual ground communications and emergency support to the DOCC facility, whether in-orbit, enroute to a planetary destination, at a permanent planetary base, or for any remote terrestrial application. This ground support includes access to specialised medical data (such as hospitals and a ground-based doctor pool), system upgrades and maintenance information, in-flight training updates, access

to detailed flight-crew profiles, resupply functions, and overall system management.

- *Providing the remote facility with specialised medical data and expertise will be a vital function of the ground control facility.*

These resources will come from many sources including, ground-based doctors and hospitals. This medical support will be part of a larger, worldwide medical support group, such as an international doctor pool. It is anticipated that the ground-based doctor pool will be a range of 38 international specialists (2 each from 19 identified and diverse specialities: Aerospace Medicine, Dentist, Laboratory Medicine, Microbiology, Hyperbaric Medicine, Ophthalmology, Neurology, Orthopaedics, Cardiology, Pulmology, Medical Imaging-X-ray, Medical Imaging-Echograph, General Surgeon, Urology, Internal Medicine, Muscle Physiologist, ENT-Specialist, Dermatology, Radiation-Specialist), who will be affiliated with hospitals, and who will work as 24-hour on-call staff. It is expected that they would support the GCC staff in emergency situations, and provide the specialised knowledge that the flight surgeon or the in-flight staff would not possess. Since these will not be dedicated staff to the GCC, it is expected that this doctor pool will be compensated on a fee-for-service basis

With the assistance of participating hospitals, this specialised knowledge can be utilised through modern telemedicine techniques, including audio communications and real-time video uplink/downlink capability. Utilising modern robotic surgical hardware, these same doctors will have limited capability to participate in the on-board medical procedures through telepresence technology. Depending upon the specific mission scenario, the delay time for signal transmission and return, and the required procedure, this telepresence technology could provide the remote facility with a wide range of expertise and surgical capability without having to place those resources permanently in the remote environment.

- *It would be the function of the GCC to first identify the need for external specialised knowledge through its constant contact with the remote facility, and to co-ordinate the transfer of this knowledge to the remote facility.*

Once the need is identified, the proper knowledge base is brought on-line and transferred to the DOCC through the GCC directly to the on-board user. It is anticipated that the doctors and hospitals with this specialised knowledge and expertise would provide this service on a voluntary basis similar to the ground on-call medical support provided to orbiting shuttle missions.

- *The DOCC telemedicine system will downlink images, sounds, and video conference sessions on a regular basis, as well as in emergency medical events.*

On the ground this digital information will be evaluated by the GCC team as well as by a world wide computer link network of the best

experts, which will give their advice and consultation when needed. This network will be established in advance and will be regularly tested to be ready for any medical event.

The ground operations support team will update the telemedicine and medical computer data base on the DOCC regularly.

- *The GCC will also provide support for the maintenance and upgrades to the remote facility.*

The ground centre will maintain technical details and specifications of the remote medical system hardware and software. The GCC can initiate refurbishment schedules and procedures as well as monitor the system operation remotely for potential problems.

While the remote facility will have on-board maintenance and repair procedures, the GCC will have the detailed manuals, data bases, and/or procedures to provide more in-depth system knowledge. The ground centre will also have access to the system manufacturer technical support staff for specific data that can be transferred to the remote facility for unique problems. From the point of view of the remote facility, the GCC will be the design centre with full capability to answer all questions regarding system operation and repair.

- *In addition to the ground control of the remote facility, the GCC would also provide the ground control for such functions as transportation and resupply management, training co-ordination, and budget oversight.*

The GCC would be the focal point to co-ordinate the needs of the remote facility with the ground resources required to support remote facility operations.

The GCC will maintain a database of the available supplies at the remote facility. Anytime a commodity is utilised at the DOCC, the used item will be documented through the use of a barcode system and removed from the available resource list. This decrease in resource stock availability will be transferred to the GCC either real-time or periodically. Based on this knowledge, the GCC will determine the necessity for resupply of the remote facility (if possible, depending upon the specific mission scenario). The ground centre will then co-ordinate the resupply of specific commodities based on either in-stock supplies or determine the need to purchase from the necessary manufacturers. The GCC will co-ordinate the transportation of these supplies to the remote facility with the governing agencies. By allocating space on existing transport vehicles or planning a unique resupply mission, the GCC will ensure that the DOCC facility will have all the resources necessary to ensure the health maintenance of the remote crew members.

The GCC will also be the focal point for all crew training. The ground control centre will be the centralised facility for the training requirements of the remote medical staff. These requirements may come from several originators, such as the individual agencies, the DOCC system manufacturers, or the GCC itself. Based on these requirements, the ground centre will manage the certification of the crew training.

Crew training may be performed by several different agencies (based on national or political priorities), but it is anticipated that the GCC will ensure all training meets certain standards and complies to a detailed certification program. It is the responsibility of the GCC to manage the training certification program.

Day-to-day budget functions of the DOCC facilities will also be managed by the ground control centre. The GCC will provide overall budget oversight including all expenditures, federal allocations, commercial and private contributions, as well as cost overruns for both the remote care facilities and the ground control centre. All costs associated with maintenance, training, upgrades, ground operations support, and resupply will be closely managed by the GCC.

Chapter 6 will develop the role of the GCC, with respect to its interactions between the ground and space segments, in greater detail. Modifications to the core functions of the GCC required by specific mission applications will be discussed in Chapters 7 and 8.

References

- Bowersox et al., "Applications of a Remote Telepresence Surgery System in Vascular Surgery," J. Vascular Surgery, 1995.
- Green et al., "Telepresence Surgery", IEEE Engineering in Medicine and Biology, 324-329, May/June 1995.

Chapter 6

DOCC Operations

This chapter will detail the operational aspects of the DOCC, for both space and ground segments. From an operational point of view, the aim of the DOCC core is to ensure an efficient use of resources and personnel while supporting DOCC functions. This includes establishing procedures for facility use, supplying and maintaining the facility, and training the users of the facility. In order to clearly state how each phase of the DOCC will be implemented, DOCC operational aspects have been broken down into the different mission phases: pre-flight, in-flight, and post-flight.

6.1 PRE-FLIGHT OPERATIONS

Before the DOCC can be used effectively, both the facility and its users must be adequately prepared. Pre-flight operations will involve selecting and training the users, verifying the design of the facility, and supplying it initially.

In the following text, “user” refers to a person working in a remote facility that is serviced by the DOCC. In other words, it refers to the cosmonaut, astronaut, explorer, scientist, soldier, or professional who benefits from the DOCC medical facilities. It *does not* refer to infrastructure or Ground Control Centre (GCC) personnel.

6.1.1 User Selection

6.1.1.1 Selection Criteria

The selection of in-flight users of the DOCC will be made by the Ground Control Centre. Users will be selected according to three general mission characteristics:

- Short-duration mission (less than three months)
- Long-duration mission (more than three months)
- General population

For a short-duration mission, users can be selected individually. As long as they meet the health requirements outlined in Section 1.3.2 and the psychological requirements outlined in Section 1.3.3, they may be selected purely on the basis of their professional skills and mission suitability. Thus, selection will be carried out on a “select-out” basis, excluding only those users who do not meet the selection criteria.

In general, a long-duration mission will have the most stringent user selection requirements. In such a situation, it may not be possible to select individuals as crew, since interpersonal conflicts will play a much more important role in crew dynamics. A two-tier selection process will then be in effect. Individuals will be selected to meet the health requirements of Section 1.3.2 and the psychological requirements of Section 1.3.3. In some cases, these might be “select-in” criteria, where the user must actively show some characteristic, as well as “select-out” criteria. The users thus selected would then be placed in crews and trained together for some time. A crew would finally be selected based on their performance *as a team*: their ability to work together, to handle stress, and to manage conflict. This ability to function well as a team will be tested in two areas: within the crew, and between the crew and the ground personnel.

A mission involving a general population of some sort is, by definition, an *unselected* population. In such a case, the DOCC GCC would require extensive knowledge of the population in question, and the senior medical staff would have to prepare to deal with a wide range of medical problems.

Particular selection requirements exist for those applying to Specialist or Medic positions (see Section 6.1.2.1 for explanation of these positions). Those applying to Specialist positions must be medical doctors, with one year of experience in primary care, one year of experience in internal medicine, and one year of experience in surgery. It is recommended that persons applying to these positions follow a Space Medicine Residency Training Program such as that outline in Section 6.1.2.2. Those applying to Medic positions must have an engineering, physical science, mathematics, chemical science or computer science background.

6.1.1.2 Selection Resources

User selection will be carried out by the DOCC GCC under the supervision of the GCC medical staff. This staff would consist of eight doctors: five physicians, two psychiatrists/psychologists, and one dentist. It would also consist of three laboratory technicians and two administrative staff. Facilities for physical examination, psychological examination, and laboratory testing would also be required.

6.1.1.3 Selection Process

Selection of users for short-duration missions would be a short process: three days of medical examination, followed by two days to analyse the results. The selection of users for long-duration missions would take considerably longer: two weeks of physical and psychological examinations, possibly followed by one month of in-team training with a final selection afterwards.

6.1.2 User Training

One of the most important factors that will guarantee the success of a remote medical facility is adequate user training. The current method of training medical crew used by NASA [Simmons, 1995] consists of designating two members of the crew as Crew Medical Officers (CMO's). Each of these CMO's receives sixteen to eighteen hours of medical training, and is responsible for providing in-flight medical care. Typically, neither of the CMO's is a medical doctor. The limited expertise of the average CMO presents a challenge to providing adequate in-flight medical care, particularly during long-duration Space Shuttle flights and International Space Station missions where serious medical problems are expected to occur. Obviously, a more comprehensive training program is required to address these problems.

Training for the users of the DOCC facility will be overseen at the DOCC Ground Control Centre, and will be administered to all in-flight DOCC users. The training will concentrate on three areas: medical training, facility usage training, and psychological mission preparation. Medical training will consist of the recognition and treatment of a variety of medical conditions. Facility usage training will consist of training in on-board equipment operation, tool handling, and emergency procedures. Psychological mission preparation will consist of preparing the user mentally and emotionally for the mission-specific remote environment.

6.1.2.1 Medical Training

While every attempt is made to insure that the DOCC medical facility will be "user friendly", each user will nevertheless require some medical background in order to take advantage of the facility. In order to make DOCC an effective facility for the promotion of human health and performance, the quality of medical training must be as high as possible. The higher the medical skills of the users, the slower will be the consumption of medical supplies and

laboratory resources. Naturally, the quality of training will be constrained by time and budget.

Medical training will be administered to DOCC users on one of three levels:

- Basic Crew
- Medic
- Specialist

The level of medical training appropriate to each user will be dependent on the user's background, and on the nature of the mission in which that user will participate.

Basic Crew training will consist of basic anatomy, medical first aid training, and observational training for the recognition of the signs/symptoms of various medical disorders. In particular, the first aid training will cover the assessment and treatment of shock, cardiac arrest, respiratory arrest, choking, minor trauma, eye injuries, sprains, burns, and lacerations. The user will be CPR certified, and will be trained in the proper handling and transportation of injured persons in the DOCC environment. If the mission of the user is one that involves partial gravity, the user will be trained to use equipment in that environment, and will be trained to perform emergency procedures and CPR using physical restraints. The user will also be trained to recognise the signs of various conditions such as Space Adaptation Syndrome, decompression sickness, and emotional depression.

Basic Crew training will be carried out at the DOCC GCC and at a designated first aid training institute. This medical training will take place concurrently with other mission training, and will last approximately two weeks.

Medic training will be considerably more detailed. It will consist of a detailed anatomy course, several courses covering primary patient care, training in the administration of drug and other treatments, and practical courses in emergency care, patient handling, and rehabilitation. At the completion of these courses, the user will engage in a one month emergency room rotation at a designated hospital. Half of that rotation will be under the supervision of the nursing staff; the other half will be under the supervision of a medical doctor. If the user's mission is one involving partial gravity, the user will run through likely necessary medical procedures for one day on board an aircraft flying parabolic trajectories to simulate the appropriate partial gravity conditions. This parabolic training will occur in the last two weeks before the user begins their mission.

Medic training will be carried out at the DOCC GCC, various university-level medical teaching institutions, a teaching hospital, a hospital emergency room, and the parabolic aircraft trainer. Much of this training must be full time, and to the exclusion of all other mission training. The training will last approximately three months.

Specialist training will be administered only to medical doctors with three years previous experience: one year each of internal medicine, primary patient care, and general surgery. It is suggested that the applicants have experience in a Space Medicine Residency Training program such as the one described below in Section 6.1.2.2. Specialist training will include a general overview of standardised primary patient care, as well as in-depth courses in dentistry, psychiatry, pharmacy, surgery, emergency medicine, and space medicine. The user will become familiar with the DOCC medical environment, and with any accommodation which must be made in order to allow the DOCC to function without nursing support. For missions in a partial gravity environment, the user will train extensively aboard the parabolic aircraft trainer. The user will fly a minimum of twenty "days" of parabolic flights, reviewing surgical, dental, and emergency techniques in the appropriate partial gravity environment.

Specialist training will be carried out at the DOCC GCC, various university-level medical teaching institutions, an institute for space medicine, a teaching hospital, a hospital emergency room, and the parabolic aircraft trainer. This training will be carried out concurrently with other mission training, and will last approximately one year.

6.1.2.2 Space Medicine Residency Training Program

To be able to serve on the DOCC, as a space physician, for long duration space flight, one would need to graduate from the Space Surgeon Training Residency (SSTR) program, which will eventually be developed. This new speciality would need to meet the international medical standards and requirements of the international participants and users of the DOCC.

Up to this point there are only a few programs which deal with space medicine. In the U.S. there are two programs for space medicine: the aerospace medicine residency program in Wright State University (WSU) in Dayton OH, and the upcoming new program in The University of Texas - Medical Branch (UTMB). However, there is no place on the globe yet where one can get full training, from beginning to end, to become a space doctor.

The proposal for space medicine training program which will be described below for the DOCC project, will be based on the need for a medical doctor for long duration space flight in low Earth orbit, at a lunar or Martian base, and even for interplanetary missions.

The residency training should be supervised by an International Board Committee for Space Medicine (IBCSM), which would have to be organised and established.

There will be two pathways to enter the residency program. The first is as a graduate of medicine who has been selected to start astronaut/cosmonaut training, and would like to qualify for Specialist medical training. The second pathway is a medical doctor, who has proven proficiency in all the elements of

the program, and would like to be selected as an astronaut/cosmonaut specifically as a medical Specialist. The decision of which path to go by will be decided by the different agencies and governments.

In the first pathway, during the training, each resident would have to be re-examined for fitness for long duration space flight every twelve months in order to be able to continue the program. During the second year all residents will submit their aerospace medicine Master's thesis, to be able to start their second block of training.

By the time the resident graduates from the program, he would be ready to participate in a long duration space mission. By this time the graduate would have finished astronaut/cosmonaut training as well as the space medicine residency training.

The Training Program for a Space Medicine Specialist (SMS)

The training is based on a five-year program, divided into three blocks. The first block is a two-year basic training and Master's degree in aerospace medicine. The second block (the third and fourth years) concentrates on primary care and rotations, and the last one-year block is the practical year. Each year is divided into two sections which are divided into four divisions.

The DOCC medical Specialist would have to be able to perform a lot of disciplinary medical tasks in different medical fields. This complexity is taken into consideration, as the residency training program emphasises the main six subjects with which a resident would have to be familiarised, as shown in Table 6.1. On the other hand it is undesirable to make the training a step-by-step strategy, so that by the time the six subjects are finished, the first one is forgotten.

This philosophy influences the basic structure of the program which will be a spiral shape with continuous education during the residency program in all the different medical subjects as demonstrated in Table 6.2.

The Space Medicine Residency Training Program for the DOCC project will be based on the need for a medical doctor for long duration space flight in low orbit, for a lunar or Mars base and even for interplanetary missions. The requirements mentioned below can be achieved before one applies to the space corps or during that training. One should remember that the space physician would be part of the astronaut/cosmonaut crew and would not serve only as a space doctor in the near future. Only when there will be space colonies will all the doctor's time be devoted to the medical tasks.

Residency Program	Duration (months)
1. Aerospace Medicine M.Sc. Prog.	12
2. Internal Medicine	12
3. Surgery	12
4. Primary Care	6
5. Gynaecology	6
6. Practical Year	12
Space Flight Surgeon Training	2
Space Medicine Clinic	2
Trauma Unit	2
ICU.	1
Telemedicine Practice	1
Psychiatric	1
Radiology	1
Dentistry	1

Table 6.1 Training Program for a Space Medicine Specialist (SMS)

First year		Second year		Third year		Forth year		Fifth year	
ASM	Inter	ASM	Surg	Inter	Surg	Inter	Gyn	Prc	BST
Surg	Gyn	Inter	Gyn	Surg	Gyn	Surg	ASM	Prc	Prc
ASM	Inter	ASM	Inter	Inter	Emrg	Inter	ICU	Prc	Prc
Surg	BST	ASM	Surg	ASM	Trm	Surg	Prc	Prc	Prc
ASM	Aerospace Medicine			Inter	Internal medicine				
Surg	Surgery			Gyn	Gynaecology				
BST	basic spacecraft training			Emrg	Emergency training				
Trm	Trauma centre			ICU	Intensive care unit				
PRC	practical year (8 rotations)								

Table 6.2 Training Curriculum for a Space Medicine Specialist (SMS)

6.1.2.3 Facility Usage Training

Each DOCC user, regardless of the level of medical training received, will receive training in the use of the medical equipment provided by DOCC. This will consist of training in emergency procedures, in the use of the available medical tools, in the use of the DOCC on-board equipment, and in the maintenance of that equipment.

In addition, some users will be designated as engineering personnel:

- Medics as primary engineering personnel
- Specialists as secondary engineering personnel

As far as emergency procedures are concerned, all users will receive the same level of basic training; additional training will be provided to the primary and secondary engineering personnel. Essentially, this training will cover DOCC facility emergency situations, including, but not limited to, fire, cabin decompression, loss of power, loss of the life support system, solar flare

events, and cabin air contamination. The user will be trained in emergency protocols, problem containment, backup equipment usage, and safe handling and evacuation of patients. Generally, this training will be within the larger context of the facility supported by DOCC. However, in particular circumstances, exclusive DOCC training may be required.

The training of users in the use of available medical tools will occur in conjunction with the user's medical training, at the appropriate level. Particular attention will be paid to the use of tools altered or wholly developed for the DOCC environment.

Each user will receive a general overview of the DOCC equipment and the telemedicine system. They will also review some straightforward equipment maintenance information. Users with Medic- and Specialist-level medical training will receive in-depth tutorials in the use of DOCC equipment, including computer tools and software, virtual reality simulation equipment, medical monitoring equipment, the communications system, and equipment monitoring devices.

Primary engineering personnel will be responsible for the regular maintenance of the DOCC monitoring, telemedicine, and diagnostic equipment. However, it will often be necessary for the senior medical personnel to also have an extensive knowledge of the on board equipment. While much of this maintenance may be automated, training will be offered to secondary engineering personnel, which will cover all calibration techniques and equipment failure scenarios.

6.1.2.4 Training Resources

Pre-flight medical training for all three levels of medical training will occur at particular training sites designated by DOCC management. These training sites will include a recognised CPR/First Aid Training Institute, university (or equivalent) level medical, pharmaceutical, nursing, dentistry, rehabilitation, and nutritional teaching institutions, a teaching hospital, a hospital emergency division, and an institute for space medicine. Users will be certified at each site once their training is complete.

Pre-flight facility usage training will occur primarily at the DOCC Ground Control Centre. It will consist of extensive use of simulated DOCC environments, both physical and computer-generated. Particular users will be sent to the offices of the diagnostic and monitoring equipment manufacturers in order to gain first-hand detailed knowledge of their hardware. It is expected that these users will learn to operate this equipment under all conditions and will be able to maintain that equipment, using both Orbital Replacement Unit (ORU) removal and non-ORU on orbit maintenance measures.

Both medical and facility usage training will continue in-flight. While some of this training will take the form of group drills and seminars using actual flight hardware, heavy use of the virtual reality system is anticipated for individual

training. As a group, DOCC users will be required to successfully complete emergency facility procedures every six weeks, and medical procedures every four weeks. Emergency facility procedures include fire, power loss, and patient evacuation drills. Medical procedures include likely medical emergencies, particularly those occurring due to decompression, toxic inhalation, cardiac arrest, and musculoskeletal injuries.

6.1.3 DOCC Facility Start-Up

This section will describe several issues to be considered during the start-up stages and initial installation of the DOCC. These issues are, in some cases, only considerations and will greatly depend upon the circumstances of the creation of the actual distant operational care centre.

The design integration, verification testing, and initial installation will be co-ordinated by one agency or contractor. This agency or contractor will verify the design integrity and ensure that the facility performs all functions per specification. In many cases, this agency or contractor will be the same as the prime operator of the launch vehicle.

6.1.3.1 Initial Supply

The initial supply of the DOCC will be co-ordinated and managed by the Ground Control Centre. The supply and stocking of the medical facility will likely be a contractor function. The process of initial supply will begin by ensuring that all medical resource and storage requirements have been met. Initial supply includes the procurement, installation, storage, verification and preservation of all flight medical resources and perishable hardware.

Depending upon the specific mission scenario, initial supply requirements will vary greatly. During short term missions or missions on Earth, the DOCC will carry the minimum resources necessary until the next resupply mission. During longer duration scenarios, initial supply will require a more extensive stock to sustain the facility throughout its mission life. The initial supply of many supplies will likely be performed just prior to the mission execution due to the perishable nature of many medical supplies.

6.1.3.2 Test Verification

Testing must be performed on all operational subsystems prior to deployment to the remote location. This testing should be performed as late as possible to ensure that no changes in design or breach of interfaces will affect system integrity. The testing functions will be contractor performed, most likely by the same contractor performing the system integration.

System testing involves two major milestones; the Integration Verification Test (IVT) and the Crew Equipment Integration Test (CEIT). The IVT is performed once the system is installed in its operating environment. It is the purpose of the IVT to verify the integrity of all interfaces between the DOCC facility and its operating support system, whether it is a spacecraft or a

Martian/terrestrial base. The IVT is essentially an end-to-end test of the entire system and ensures the compatibility of all sub-system connections.

The CEIT performs the actual compatibility testing between the crew and the flight hardware. This is the test scenario whereby the crew are able to verify the flight hardware functionality and discover any discrepancies between the simulators and the actual flight equipment. A typical CEIT involves a simulation of one or many medical scenarios which put both the crew and equipment through several real-life situations. The CEIT test should include all hardware, crew, ground support facilities and personnel that will normally be used during actual operations.

Prior to placing a complex system such as a DOCC into any remote location, every attempt should be made to test the facility and all of its support systems. The decision of not performing a certain test and the related cost-savings must be weighed against the cost of a system failure at the remote location and the ultimate consequences of that failure.

6.2 IN-FLIGHT OPERATIONS

In the following section, some aspects of operating the DOCC during its mission will be examined. In particular, the co-ordination of resources for the maintenance of the facility and the development of procedures and protocols for the use of that facility during its mission life are discussed.

6.2.1 Procedures and Protocols

The aims of this section are threefold. First, the reasons for using procedures and protocols will be examined together with how they are used operationally. Second the current human-procedure interface will be examined and a rationale will be developed for why a change is required. Third, emerging technologies are described and their applicability to the human-procedure interface in the short, medium and long term future are discussed. This will allow the description of the kinds of procedures and protocols to ensure a smooth functioning of the DOCC core facility and to look at how the procedures are used by the crew members and ground control.

6.2.1.1 Procedures

A procedure can be defined as a set of steps that are followed in order to accomplish a task. The use of procedures becomes more important during complex tasks, especially those tasks involving several people, to ensure that all the necessary steps are performed as smoothly as possible. Procedures also provide a reference for training both the individual and the team.

In manned spaceflight procedures and protocols are generally followed during all phases of routine and contingency operations. When the task is complex and perhaps hazardous then it is important to ensure that the task is carried out safely as planned. Detailed flight procedures are unlikely to disappear in

manned spaceflight activities because the crew time in space is very expensive, in the order of \$18,000 per hour, and must be optimised. In addition the environment is hazardous and the use of validated procedures can help to ensure safety.

6.2.1.2 Protocols

A protocol can be defined as a framework for making a decision based on the available information. Protocols are important when difficult decisions need to be made. An example of an area where an established protocol for dealing with a situation is necessary is in triage. If there are two injured astronauts and it is only possible to rescue one astronaut at a time then how does one choose who to rescue first? The decision could be based on the following. How serious is the injury? How long can the patient wait? What is the value of the person to the mission? How likely is it that the person's life can be saved? Is a rescue going to succeed? Will the other crew members be exposed to danger?

A framework for these decisions is required because there may be more at stake than a single life. In some cases a rescue may not be possible, perhaps because of the constraints of orbital mechanics or the available propellant to transport a patient back to the DOCC.

6.2.1.3 The Current Situation

On board the U.S. space shuttle and in the medical facilities planned for the ISS, the list of operational procedures and protocols are based around a Flight Data File (FDF). This is a set of paper manuals containing both text and pictures which are carried along during flight. The FDF contains the following major components:

- Medical Checklist

The medical checklist is used to aid the diagnosis and the range of medical problems which could be encountered. The medical requirements list defines the basic set of medical problems. For each problem a detailed set of steps for treatment would be given. There may also be general procedures which cover what to do with bits and pieces during a medical operation or other emergency, for example what is done with the syringes? Are they disposed of immediately or stored somewhere before disposal?

- Medical Equipment Manuals

The medical equipment manuals contain instructions for the operation, calibration, check-out, malfunction diagnosis and maintenance of the medical equipment of the DOCC. Where possible the equipment should be designed so that check-out and malfunction diagnosis are automated and the procedures would just specify the time between checks and how to perform a Built In Test (BIT). For example a defibrillator unit may need to be test fired monthly.

- Refurbishment, Replenishment and Logistics

Certain pieces of equipment may require replenishment of fluids or removal of waste products on a regular basis. These tasks may need to be co-ordinated with other tasks.

- Contingency Scenarios

This would include procedures for dealing with the co-ordination of crew, ground, and resources during medical emergencies which may arise. Examples include: fire in a module, toxic release, EVA mishap or loss of communication. The list would be very long and deal in detail with how to minimise the effects of an accident and recover the situation. The emergency procedures may also specify who co-ordinates the communications, who co-ordinates with the Ground Control Centre (GCC). Each crew member will require some sort of role during the emergency and will also need to know his functions in that role.

- Countermeasures

This would include the schedule for countermeasure usage, the workload, and the calibration of the countermeasure equipment, for example the Lower Body Negative Pressure device (LBNP) or treadmill.

- Medical Monitoring

This would define the schedule for performing medical check-ups and the procedures to perform the checks.

An additional important component is the link with the GCC. It is usual for the crew to confirm nearly every step in a procedure with the ground before executing it. This means that the tasks are accomplished more slowly but it adds an extra layer of safety.

The Flight Data File is validated and tested before flight through simulations and system validation tests. The contingency procedures may only be developed for single failures. This is mainly because the procedure book would get too large if all double failure cases were considered. There may be exceptions to this if a particular double failure is likely to occur. More complex failure cases would rely on real-time analysis of the situation by experienced ground support personnel and the experience of the crew to solve the problem.

The current system of storing and using the Flight Data File has several advantages. Paper manuals are very robust and portable. The FDF can easily be taken into an airlock and requires no power input. There is a high familiarity with the current system. The procedures can also be updated and annotated very easily by written notes in the margin, which is very important operationally. The space and mass required for storage is acceptable.

6.2.1.4 Is there a Rationale for a Change?

Although the current method of the FDF has many advantages there are at least two reasons which provide the rationale for change. That said, it is very doubtful whether the current FDF will disappear completely because of the robustness and portability mentioned above; however, it may become the backup solution.

A) Crew Autonomy

In current shuttle operations the ground link is available over 95% of the time and ground control is used to confirm nearly every step in the procedures. The Mir space station has only twenty minutes of ground coverage per orbit and the crew have more autonomy in following procedures. The ground is only informed that procedures have been started or completed, or if there are problems.

In the short term there is a definite requirement for increased crew autonomy in executing procedures aboard the upcoming International Space Station (ISS). More crew autonomy means less ground support and speeds up the execution of the flight procedures, allowing a higher productivity. Increased crew autonomy requires a change in manned spaceflight operation philosophy on the part of the U.S. Some of the concept discussed in the next section could help increase crew autonomy.

In the very long term there may be a rationale for complete crew autonomy as the number of workers in space increases.

B) In-Flight Procedure Training

When planning the response to a complex task, it is very important to practice the procedures. For emergency scenarios which may only happen infrequently this may take the form of drills which can be practised before and during flight. It is possible to imagine a simulation system similar to the current flight simulators used to train aircrew. This may be especially important during long duration missions, where crew may forget the exact sequence of events. In the case of the international Mars mission it will be very important to continue to train and practice procedures during the voyage out and back, and there should be more time available to do this.

On Earth it is usual for surgeons to perform basic medical procedures often so that a high level of experience and competence can be maintained. For a long duration mission it is likely that medical emergencies will occur rather infrequently and so it may be difficult to sustain a very high level of competence in the medical emergency procedures.

The training concepts are discussed in Section 6.1.2, including Virtual Reality and other forms of computer based training. The flight procedures form the framework for these training methods. Advanced concepts for interactive

multimedia presentation of procedures will be useful for in-flight training. Training in DOCC equipment operation could be a mixture of computer-based training and virtual reality. The crew would practice a complex maintenance activity before performing it on the hardware. This will take more time but will ensure success. It is important that these training systems be interactive to increase the training effect.

6.2.1.5 The Human-Procedure Interface

The current Flight Data File approach can be thought of as follows: the procedures are stored in a paper manual in the spacecraft and additional information is stored in the GCC. The procedures can be searched by using the index. The information is output either by the crew member reading the procedure or by listening to another crew member or the GCC reading the procedures out over a communication link. Additional information may be input by the crew member annotating the procedures by writing in the margin, or making comments to the ground, who then update the procedures.

Any electronic method of using procedures must consist of a searchable store of data with a way to output them to the user and a way for the user to input a request for data and add new information. There may be other requirements for advanced systems, but this is the minimum set.

6.2.1.6 A Look into the Future: Advances in Information Technology

A) Present Day Technology

A present day technology solution that could be implemented straight away would be an off-the-shelf notebook computer with a CD-ROM drive. The notebook computer would need to be made more robust and made safe for spaceflight. The Flight Data File could be stored on a single CD containing all the procedures in a HTML-based hypermedia format. Graphics, video, audio and even simple virtual reality, for example VRML, could be integrated to give a more interactive method of browsing through procedures. Training in equipment usage and maintenance could be enhanced by interactive Computer Based Training (CBT), equipment emulation and simulation software which are all available today. If the notebook is connected to the ground station through a communication link additional files and simulations could be uploaded as required. General purpose power and network connections could be placed in various locations around the DOCC facility, or a wireless network approach could be used to distribute data.

The main disadvantages with any electronic information system in space are reliability and portability. A CD is completely useless without a piece of hardware to read it. If there is a hardware malfunction or a loss of power the paper procedures must be used. Therefore, even if electronic storage and retrieval is used a backup paper copy will be used for the foreseeable future. On the portability side it is not possible to take electronic devices into the EVA airlock because of the risk of fire. Notebook computers are starting to be used on the U.S. Space Shuttle with positive results, however there are

problems with radiation induced component failures. There is also a high cost associated with bespoke technical training software, although hopefully advanced editing tools and techniques will help reduce the development cost.

An alternative solution would be one of the Personal Digital Assistants (PDA's) which are currently being brought to the market place; however, these seem less flexible in usage than a current notebook computer.

B) The Short Term (less than three years)

Several emerging technologies could be incorporated to make the system more portable and usable in the short term. An example of a very promising emerging technology are wearable computers such as the Xybernaut®, shown in Figure 6.1. Wearable computers are beginning to be used for such tasks as aircraft construction and maintenance. The computer is worn around the waist and the display is a small head mounted monitor, such as a Private Eye®. Information can be input by a hand mounted chording keyboard such as a Twiddler®, or by voice control. The device is essentially hands-free. Such a device could be used aboard DOCC, for example, to give the doctor access to medical procedures and monitoring information during an operation. It would also be useful for diagnosis of equipment problems and equipment maintenance. The system could be networked to the DOCC through an infrared link, giving complete mobility. A similar system could also be used during EVA operations.

Disadvantages would include the reliability and portability issues addressed above. There may also be problems with the use of head mounted displays in microgravity, as the human vestibular system relies more on visual inputs.



Figure 6.1 Xybernaut Wearable PC

An alternative approach which may be better is some sort of voice activated system where the computer is used to find the relevant material and display or broadcast it in real time. This may have the potential for time savings and ease

of use over a wearable computer. Input and output terminals could be placed in various locations about the facility.

C) The Medium Term (less than ten years)

In the medium term there will be advances in miniaturisation and software which will increase the capability of wearable computing technology. Technologies which are being discussed today include direct retinal projection for image display, 3-D image display and improved voice recognition and control. However the major advances will probably be in the area of the human-machine interface and artificial intelligence. The aim is to increase the potential of the human mind with computers. Three buzzwords are Augmented Memory, Augmented Intelligence and Augmented Reality. These technologies require a computer system to monitor more closely what is happening around the user, both vision and sound, and to use the speed, precise storage and searching capability of computers to provide additional relevant information to the user. An example of augmented memory would be the computer giving a description of a detailed operational procedure as the user requires it. An example of augmented reality would be an overlay of a wiring diagram over the visual field to give the user information on how the components of the DOCC are connected together, or doctors could view the inside of the patient before starting to operate. The system could also be used to keep track of the storage location of particular object, such as the defibrillator, so that a route to the object, or a lost item could be displayed on the users visual display (See Figure 6.2).

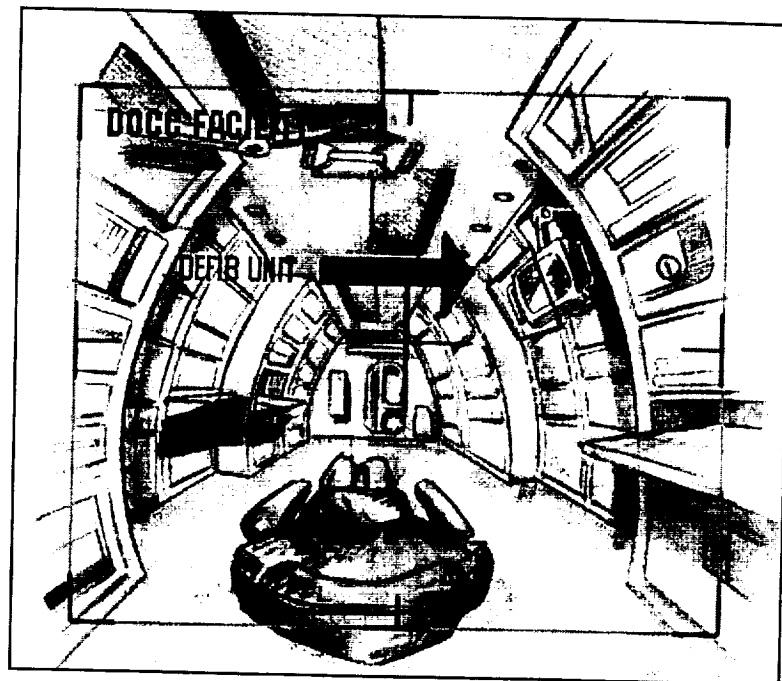


Figure 6.2 Use of Augmented Reality for Location of DOCC Hardware and Resources

D) The Long Term (thirty years)

There is current research into creating a direct brain interface for controlling computers and receiving information, either through the use of implants or otherwise. This would improve the human-machine interface still further. With increased development some form of Collective Intelligence can be imagined. This is the term used when more than one user of a wearable computer is connected together, giving access to the other users' knowledge and thoughts. There may be applications of this technology in psychological support in remote environments, for example, of astronauts on a space station or a Mars mission (see Psychological Countermeasures Section 1.4.6.5).

E) What is Driving the Development of these Technologies?

We can be fairly sure that manned spaceflight will not be the only driver in the development of these technologies because of the small number of users. Other major sectors which will drive the development are the military, construction and service industries, medical technology and the entertainment industry.

6.2.2 Maintenance and Logistics

6.2.2.1 Objective

One of the most important issues one must consider in the DOCC design is how to maximise the DOCC availability. Put another way, one must consider how to prevent a failure occurring (increase reliability), and how to repair the failure swiftly when it happens (increase maintainability). Table 6.3 shows typical methods to accomplish this objective.

Objective		Methods	
To keep high Availability	To increase Reliability	Reliability design	Use high Reliability parts
			Redundancy design
			Eliminate SFP*1
		Test, Quality Control	
	To increase Maintainability	Maintainability design	FDIR*2 design
			Optimise Maintenance unit
		Adequate Maintenance Plan	
		Adequate Logistics (Resupply, Return and Storage) Plan	

*1 SFP: Single Failure Point

*2 FDIR: Failure Detection, Isolation, and Reconfiguration

Table 6.3 Methods of Keeping High Availability

From the DOCC operational aspect, this section addresses the Maintenance and Logistics Plan which appears in the above table. Furthermore, this section

describes functions which are required of the DOCC based on this plan and also gives a Maintenance and Logistics Items List (MLIL).

6.2.2.2 Basic Concept

The key design concept of DOCC is, to quote the mission statement, (see Introduction and Chapter 3), “To be a modular medical facility” and “To maintain human health and performance.” The basic Maintenance and Logistics concepts are derived from the following:

1. To maintain human health and performance

For this purpose, DOCC shall maintain high availability. In time critical operations, the system should be prevented from shutting down. Therefore, all time critical hardware shall have adequate redundancy and ease of maintenance. Logistics also shall be planned to minimise system down time.

2. To be a modular medical facility.

The term “modular” implies high adaptability, that is, not to depend on the types of missions the DOCC will be integrated into. To keep high adaptability (independence from any particular mission design), users of the DOCC shall not require special skills, tools, and work areas to perform maintenance.

6.2.2.3 Maintenance

1. Preventive Maintenance and Corrective Maintenance

Basic maintenance activity has been categorised into Preventive Maintenance and Corrective Maintenance. Preventive Maintenance is performed periodically and includes inspection and calibration, replenishing consumables and replacing limited life items. Corrective Maintenance is performed after a failure occurs. The number of Corrective Maintenance activities are predicted based on failure rate data.

2. Maintenance concept

Maintenance tasks are classified as follows:

- Replacement: for failed ORU’s, limited life items
- Repair: for failed non-ORU items
- Replenish: for consumables, spend out items
- Inspection and Calibration: for items which have been repaired or have undergone Preventive Maintenance

3. ORU concept

In order to minimise the time crew spends on maintenance, the maintenance tasks are mainly performed through the replacement of the Orbital Replacement Units (ORU’s). The ORU’s shall be designed to

make maintenance tasks easily performed. More complicated maintenance tasks like soldering, welding and drilling shall not be planned as routine on orbit maintenance tasks. By definition, all items which are not ORU should be called “non-ORU.” The non-ORU are those components of the DOCC which cannot be designed in a modular format. The obvious non-ORU items include some medical tools, consumables and drugs.

The criteria used to decide whether a component should be designated as ORU or non-ORU depends on the mission. For example, the design of an equipment rack should be designated as ORU in the cases where storage capacity exists, and as non-ORU if the mission does not permit enough storage. In the latter case, all components of the rack should be designed to be very reliable and easily and quickly repairable.

4. Maintenance Tools

The DOCC shall not need tools other than those normally found on board to perform routine maintenance tasks.

5. Mean Maintenance Crew Hour per Year

Since crew time is a valuable resource, the design of the DOCC should minimise the Mean Maintenance Crew Hour per Year (MMCH/Y). The magnitude of MMCH/Y depends on the mission design. Main methods to minimise the MMCH/Y are to reduce Mean Time To Repair (MTTR) and to extend Mean Time Between Failure (MTBF). The MTBF of the entire DOCC is probably difficult to make longer due to the increased complexity of the system. Therefore the significant reduction of the MTTR is very important in the DOCC design.

6.2.2.4 Logistics

1. Resupply, Return and Storage

Logistics, as it applies to the DOCC, consists of Resupply, Return and Storage. Resupply and return involve transferring the items needed between on-site and Earth. Storage consists of on-site storage and Earth-based storage.

2. Resupply and Return Logistics

Resupply and return logistics refers to the implementation of the resupply and return functions. The DOCC core elements should not rely upon any specific vehicle type. The method of resupply and return depends on each mission design. The DOCC shall be designed to use the resupply and return methods made available for any mission.

3. Optimisation of Resupply and Storage

Basically, resupply intervals, storage volume and location (on-site vs. Earth-based) will be decided depending on the mission design. Trade-off studies should be carried out to optimise resupply intervals and storage volume/location to minimise total cost from design to implementation. The trade-off studies are performed to consider and compare factors such as mass, volume, power and crew time (man-hours) for all possible

scenarios requiring resupply and storage allocation. Optimisation depends on the mission type:

Short term mission or transportation mission: All components will be stored on-site. No resupply logistics required.

Long term, short distance mission: On-site and Earth-based storage ratio is decided from trade-off studies considering storage and resupply costs.

Long term, long distance mission: Although resupply capabilities may be available, most components shall be stored on-site. On-site and Earth-based storage ratio is decided from trade off studies considering storage and resupply costs.

6.2.2.5 Required Functions

The DOCC provides the following functions to achieve the maintenance and logistics concepts described above. Table 6.4 shows an application matrix of these functional requirements for some mission scenarios.

1. *Failure Detection, Isolation, and Recovery (FDIR)*

Failures of complicated hardware such as laptop computers, echographs, and medical computer systems, shall be detected automatically to minimise maintenance activity. In the case of hardware malfunctions where time is critical, the failure shall be isolated and repaired automatically where possible.

2. *Support ORU replacement*

The DOCC system mainly consists of ORU's. Each ORU shall be designed for easy removal and replacement. For example, minimising the number of fasteners, designing convenient handles and using quick disconnect technology. All ORU's shall be designed for easy performance of inspection and calibration.

3. *Support non-ORU repair, replenish and reuse*

Some items of the DOCC can not be designed using the ORU concepts. (see Section 6.2.2.3) Concerning these non-ORU items, they shall be designed to facilitate repair and replenishment. All non-ORU's shall be designed for easy performance of inspection and calibration.

4. *Resupply and Return*

Resupply and return will be determined using trade-off studies concerning logistics (see Section 6.2.2.4). The DOCC GCC shall provide these functions.

5. *Storage (on-site)*

On-site storage will be determined using trade-off studies concerning Logistics (see Section 6.2.2.4). The DOCC shall provide for adequate storage on-site.

6. Storage (Earth-based)

Earth-based storage will be determined using trade-off studies concerning Logistics (see Section 6.2.2.4). The DOCC shall provide for adequate earth-based storage.

Core Function Requirements	Orbital Mission	Mars Mission (Transportation)	Mars Mission (Mars Base)
Failure Detection, Isolation, and Reconfiguration function	X	X	X
Support ORU* Replacement	X	X	X
Support non-ORU Repair, Replenish and Reuse	X	X	X
Resupply & Return	X	N/A	X
Storage (on-site)	X	X	X
Storage (Earth-based)	X	N/A	X

X Applicable, N/A: Not Applicable

* ORU: Orbital Replacement Unit

Table 6.4 Maintenance and Logistics Functional Requirements Application

6.2.2.6 Maintenance and Logistics Items List (MLIL)

Maintenance and logistics items for DOCC core module are shown in Table 6.5. The table identifies what kind of maintenance or logistics support will be needed.

Medical Item	Replace-ment or Repair for fail *1	Replenish for consum-ables, spend out items	Inspec-tion / Calibra-tion	Time critical item *2	Mainte-nance	Logistics (storage or resupply)
Medical Computer System						
• Laptop Computer	X	N/A	N/A	X	X	X
• Video Monitors	X	N/A	N/A	X	X	X
• Software	X	N/A	N/A	X	X	X
Portable First Aid						
• Airway Management System	X	X	X	X	X	X
• Pharmaceuticals & Supplies	N/A	X	N/A	X	N/A	X
• Defibrillator	X	N/A	X	X	X	X
• Crew Medical Restraint System	N/A	N/A	N/A	N/A	N/A	N/A
Standard Diagnostic Tools						
• Blood Pressure Measurement Device (Sphygmomanometer)	X	N/A	N/A	N/A	X	X
• Ophthalmoscope	X	N/A	N/A	N/A	X	X
• Otoscope	X	N/A	N/A	N/A	X	X

Medical Item	Replace- ment or Repair for fail *1	Replenish for consum- ables, spend out items	Inspec- tion / Calibra- tion	Time critical item *2	Mainte- nance	Logistics (storage or resupply)
• Digital Stethoscope	X	N/A	N/A	N/A	X	X
Intensive Care Unit						
• Blood Pressure Measurement Device	X	N/A	X	N/A	X	X
• Defibrillator	X	N/A	X	X	X	X
• Electrocardiograph(ECG)	X	X	X	N/A	X	X
• Electroencephalograph(EEG)	X	X	X	N/A	X	X
• Intravenous Pump	X	X	X	X	X	X
• Metabolic Gas Analyser (MGA)	X	X	X	N/A	X	X
• Oximeter	N/A	N/A	N/A	N/A	N/A	N/A
• Temperature Probe	N/A	N/A	N/A	N/A	N/A	N/A
• Ultrasound Device	X	X	N/A	N/A	X	X
• Ventilator	N/A	X	N/A	N/A	X	X
• X-ray Device	X	N/A	X	N/A	X	X
Pharmaceuticals/Supplies						
• Pharmaceuticals	N/A	X	N/A	X	N/A	X
• Intravenous (IV) Fluids	N/A	X	N/A	X	N/A	X
• Bandages, Gauze, Drapes	N/A	X	N/A	N/A	N/A	X
• Plaster, Splints	N/A	X	N/A	N/A	N/A	X
• Blood supply	N/A	X	N/A	X	N/A	X
• Refrigerator	X	N/A	N/A	N/A	X	X
• Freezer	X	N/A	N/A	N/A	X	X
Surgical Equipment and Table						
• Anaesthesia Equipment	X	X	X	X	X	X
• Endoscopic Surgery Kit	X	X	X	X	X	X
• Surgical Glove Box	X	N/A	N/A	X	X	X
• Sharp Trash Container	N/A	X	N/A	N/A	N/A	X
• Soft Trash Container	N/A	X	N/A	N/A	N/A	X
• Sterilisation Equipment (gas sterilisation)	X	X	X	X	X	X
• Surgical Image Overlay / Heads Up Display	X	N/A	N/A	N/A	X	X
• Surgical Instruments	X	X	X	X	X	X
• Surgical Table	N/A	N/A	N/A	N/A	N/A	N/A
• Urine Collection System (UCS)	X	X	N/A	N/A	X	X
• Body Bag	N/A	X	N/A	N/A	N/A	X

Medical Item	Replace- ment or Repair for fail *1	Replenish for consum- ables, spend out items	Inspec- tion / Calibra- tion	Time critical item *2	Mainte- nance	Logistics (storage or resupply)
Dental						
• Dental Ancillary Supplies	N/A	X	N/A	N/A	N/A	X
• Dental Handheld Instruments	X	N/A	N/A	N/A	X	X
• Restorative Materials	N/A	X	N/A	N/A	N/A	X
• Dental Glove Box	X	N/A	N/A	N/A	X	X
• Sterilisation Equipment	N/A	X	N/A	N/A	N/A	X
Clinical Chemistry Analysers						
• Capnograph	X	N/A	X	N/A	X	X
• Complete Blood Count Analyser	X	X	N/A	N/A	X	X
• Centrifuge	X	N/A	X	N/A	X	X
• Occult Blood Strip	N/A	X	N/A	N/A	N/A	X
• Serum Multiple Analyser (analyses both blood and urine)	X	X	N/A	N/A	X	X
• Urine Dipstick	N/A	X	N/A	N/A	N/A	X
Exercise Countermeasures						
• Treadmill	X	N/A	N/A	N/A	X	X
• Cycle Ergometer	X	N/A	N/A	N/A	X	X
• Multi-Axial Resistive Exerciser	X	N/A	N/A	N/A	X	X
• Lower Body Negative Pressure (LBNP)	X	N/A	N/A	N/A	X	X
Countermeasures Monitoring						
• Blood Pressure / Electrocardiograph (BP/ECG)	X	N/A	N/A	N/A	X	X
• Metabolic Gas Analyser	X	X	X	N/A	X	X
• Bone Densitometer	N/A	N/A	N/A	N/A	N/A	N/A
• Body Mass Measurement Device	X	N/A	N/A	N/A	X	X
ECLSS-Microbiology System						
• Fungal Spore Sampler	X	X	X	N/A	X	X
• Incubator	X	N/A	N/A	N/A	X	X
• Microbial Air Sampler	N/A	X	N/A	N/A	N/A	X
• Microbiology Safety Cabinet	X	N/A	N/A	N/A	X	X
• Optical Microscope and Camera	X	N/A	N/A	N/A	X	X
• Slide Staining Apparatus	X	N/A	N/A	N/A	X	X
• Surface Sampler Kit	N/A	X	N/A	N/A	N/A	X

Medical Item	Replace- ment or Repair for fail *1	Replenish for consum- ables, spend out items	Inspec- tion / Calibra- tion	Time critical item *2	Mainte- nance	Logistics (storage or resupply)
• Water Microbiology Kit	X	X	X	N/A	X	X
ECLSS-Radiation Monitoring System						
• Radiation dosimeters	X	N/A	N/A	N/A	X	X
• Extra-Vehicular Charged particle Directional Spectrophotometer	X	N/A	N/A	N/A	X	X
• Intra-Vehicular Charged particle Directional Spectrophotometer	X	N/A	N/A	N/A	X	X
• Tissue Equivalent Proportional Counter (TEPC)	X	N/A	N/A	N/A	X	X
ECLSS-Toxicology System						
• Capnograph	X	N/A	X	N/A	X	X
• Compound Specific Analyser - Combustion Products (CSA-CP)	X	N/A	N/A	N/A	X	X
• Compound Specific Analyser - Hydrazine (CSA-H)	X	N/A	N/A	N/A	X	X
• Volatile Organic Analyser (VOA)	X	X	X	N/A	X	X
• Personal Air Filter	N/A	X	N/A	X	N/A	X
• Portable Breathing Apparatus	N/A	N/A	N/A	X	N/A	N/A
• Total Organic Carbon Analyser (TOC)	X	X	X	N/A	X	X
• Water Sampler & Archive (WS&A)	X	X	X	N/A	X	X
Contamination Protection System (CPE)	X	X	X	N/A	X	X
Noise Attenuation System						
• Audiometer	X	N/A	X	N/A	X	X
• Hearing Protectors	N/A	X	N/A	N/A	N/A	X
• Noise Dosimeters	X	N/A	X	N/A	X	X

X: Applicable N/A: Not Applicable

*1 Replace or Repair depends on mission

*2 Time Critical: Assumed items cause to loss of life if it is not supplied in 1 day after medical needs occur as Time critical items.

Table 6.5 Maintenance and Logistics Items List (MLIL)

6.3 POST-FLIGHT OPERATIONS

The following sections will detail the operational support of both the DOCC facility and the facility users in the post-mission phase.

6.3.1 User Deconditioning

The DOCC GCC will be responsible for overseeing the deconditioning of DOCC users once the mission has been completed. Deconditioning will vary with the mission length and the nature of the environment to which the user has been exposed. Support programs will be developed for the following conditions:

- short-term exposure to micro or partial gravity (including vestibular system readjustment, cardiovascular deconditioning)
- long-term exposure to micro or partial gravity (including cardiovascular deconditioning, muscular system readjustment, bone mineralisation, vestibular system readjustment)
- exposure to extreme temperatures and pressures
- exposure to radiation
- traumatic shock
- acute and chronic stress
- extreme isolation

The medical staff for deconditioning will be the same staff that conducts user selection, and deconditioning will take place in the facilities used for selection. Once the user has attained a certain level of health, they will be debriefed and released from the program. The DOCC deconditioning staff will continue to monitor that patient for a period of six to twelve months following debriefing.

6.3.2 Facility Evaluation and Shutdown

In order to periodically evaluate the DOCC facility, it will be taken out of service at either the end of the mission life, or at the end of a three year service period, depending on the character of the mission. At that time, the DOCC will be cleared of personnel, secured, and powered down. If the mission in question is ongoing and requires continuous medical support, the DOCC facility will maintain a downgraded capability during the evaluation period.

The DOCC facility evaluation process will be conducted under the supervision of the DOCC facility manufacturer and integrator. The results of this process will be fed back into the design process for future DOCC facilities. The evaluation will be influenced by:

- effective patient treatment
- effective use of supplies
- power and resource usage

- ergonomics and
- sterilisation.

At the time of evaluation, upgrades of computer hardware and software, training tools, monitoring hardware, and equipment manuals will be made. In most cases, this should involve transportation of the new modules to the DOCC facility, the change-out of the modules in situ, and the return of the old modules to the DOCC GCC for individual evaluation.

In the event that the DOCC facility must be shut down completely, it will be evacuated of personnel, have its equipment secured, and be powered down. Data will be downloaded and stored by the data management centre. In most cases, where economically feasible, the facility will be transported to the DOCC GCC for disposal, and equipment will be re-used on future missions, sold for salvage value, donated to charitable medical facilities, or scrapped.

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Section III

Case Applications

Case Applications

Scenarios & Environments

To analyse the functionality of the DOCC facility, it was decided to apply the core design derived for DOCC to a number of selected environments. The process allowed, in each case, consideration of the additional components needed to ensure the operation of DOCC in a range of varying locations and environments.

A review of proposed future missions, following what was believed to be an evolutionary development of solar system exploration and exploitation allowed the selection of a set of proposed scenarios. From the scenarios a number of environments were defined which it was believed represented the extremes to which DOCC would be applied.

REVIEW OF PROPOSED FUTURE MISSIONS

As identified from the mission statement DOCC was intended to be adaptable to be able to operate in a wide range of environments. From a core module, specific features would be added to tailor the facility for operations in orbit, in interplanetary space or from the surface of the Earth or other planets.

To better understand the range of situations the DOCC may be used in, an analysis of possible future missions was conducted. Within the review, potential future missions were considered and their feasibility considered as well as a date assigned as to when it was believed the mission would be first achieved. The missions considered represented what was believed to be a structured development programme, starting from the pending International

Space Station through human Moon and Mars exploration to more distant scenarios, such as interstellar flight.

The results of the analysis are presented in chronological order in the Figure III.1 below.

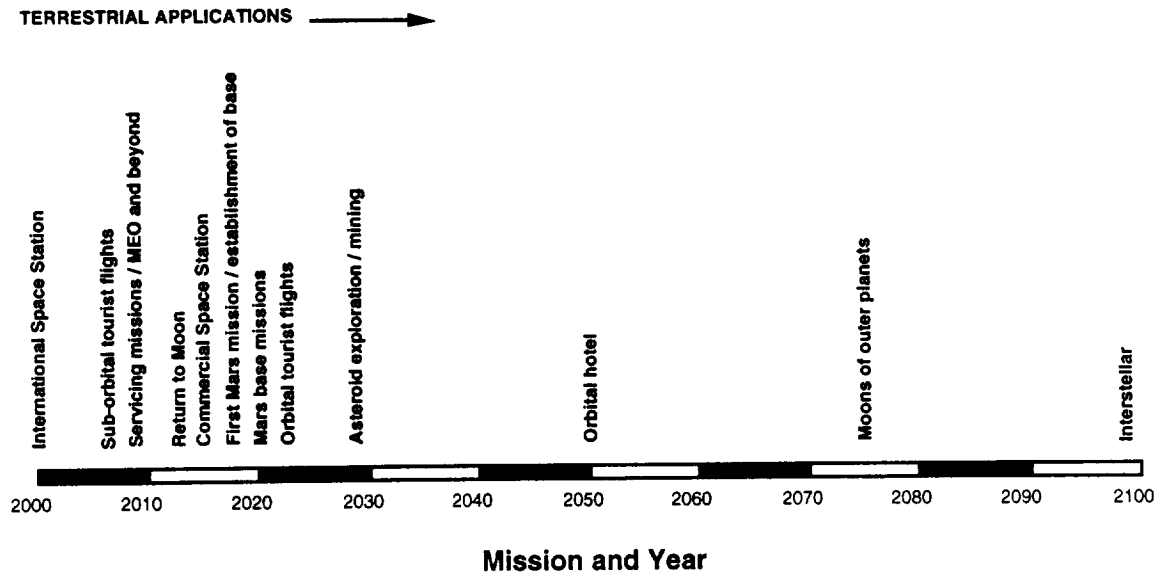


Figure III.1 Review of Future Mission Scenarios

SCENARIO SELECTION CRITERIA

From the initial list of envisaged future scenarios a smaller group of missions, representing a cross range of situations and in particular environments, were selected to show how the DOCC facility would be adapted to suit the varying influences placed upon it, see Table III.1 *Selected Mission Scenarios*. To derive the selected list, a number of criteria were applied to the above missions, and each environment evaluated.

The selection criteria applied to the scenarios included:

Mission duration

The first aspect to be considered was the duration of the proposed mission. A short mission duration of only a few days in Earth orbit was contrasted with missions of many years duration. At each end of the extreme, different medical requirements would apply, presenting differing medical requirements. In particular, the mission duration and its impact on the ability to perform an emergency return to Earth were considered.

AREA	SCENARIO	DURATION	GRAVITY	SKILLED? ¹	FEASIBLE	COMMS	COST ²	RESUPPLY
Moon	1st base	Short	1/6 'g'	Yes	20 yr +	2.5 s	\$	Week
	Permanent	Medium		No	25 yr +		\$\$	
Space Station	ISS	Medium	μ 'g'	Yes	10 yr +	ms	\$	Days
	R & D	Short		No	15 yr +		\$	
Mars	1st visit	Long	Artificial (1/3) 'g' + 1/3 'g'	Yes	20 yr +	7-40 min	\$\$	Unfeasible
	1st base			Yes	25 yr +		\$\$\$	
Terrestrial	Seatown	n/a	1 'g' + P _{OCEAN} ³	No	0-5 yr	Real time	c	Days
	Sea farm				0 yr			
	3rd world/ disaster	Medium	Hours					
	Antarctica							Weeks

Notes: 1 Skill level of astronauts. For space applications:

2 'YES' refers to professional astronauts, 'NO' refers to semi-professional 'research' astronauts

3 Cost based on comparative analysis of proposed mission scenarios

Refers to additional pressure effects due to submarine location

Table III.1 Selected Mission Scenarios

Gravitation

For each of the selected missions the level of gravitation experienced by the astronauts needed to be evaluated. The changes brought on in the medical condition of humans flying in space is well understood for a duration of up to a year in space, however some of the missions proposed would require a much longer duration. In particular, it was necessary to evaluate the length and percentage of the mission duration spent in both microgravity, artificial gravity and partial gravity situations for interplanetary missions.

Skill level

For each of the envisaged scenarios the skill level of the astronauts was evaluated, ranging from no (or very little) training for space tourists through to the very high skill level of professional astronauts, derived from years of advanced training. In between tourists and professional astronauts, a class of semi-professional astronauts was defined, consisting of astronauts who may be launched for commercial reasons, and after a minimum level of basic training.

Communications

For each of the scenarios considered, an initial estimate was made of the typical communication delay times. Missions in Earth orbit do not exhibit a significant time delay, allowing near real-time communication. Missions further away require the spacecraft to have a greater level of autonomy, or more direct input from the astronauts, including in the administering of medical assistance.

Resupply

An initial estimate of the ability to resupply was also considered, as this would have a strong influence on the level and amount of equipment which would need to be carried, driving design, transportation and operations.

Cost

A comparative study was made of the costing of the projects, to illustrate qualitatively the level of funding required for each of the missions to succeed. This estimate was used in the feasibility assessment to derive an overall view of how realistic each scenario would be.

Feasibility

Finally each scenario was considered in terms of its perceived feasibility. The analysis of feasibility attempted to account for factors such as: whether the required technology would be available by the suggested launch date, or whether large technological leaps would be required; whether public support would increase to support the mission; whether reliable low cost access to

space would be available and whether the financing of such missions would remain flat, such as the current day, or whether a large governmental commitment would catapult the mission to the foreground.

SELECTION OF ENVIRONMENTS

Of the mission scenarios shown in the table, three scenarios were selected which it was believed addressed the widest range of possible environments. The two space-based scenarios proposed represent the extremes of environment which it is believed will be met by the astronauts. A short duration microgravity situation in the orbital application is contrasted with a long duration partial gravity mission for the Mars application. In each case DOCC was applied to the specific needs of the mission, as discussed in Chapters 7 and 8. The scenarios selected were therefore:

A commercial space station, providing in-orbit research facilities of up to 20 semi-professional astronauts, for short duration stays.

and

A DOCC facility to be used during the transfer to and at the first permanent Mars base, dedicated to the health care of a core of astronauts living and working on the surface for approximately a year.

In addition, terrestrial applications of the DOCC's technology, particularly in third world development and disaster relief situations, is further discussed within Chapters 9 and 10.

TRANSPORTATION ISSUES

With these selected environments in mind, it becomes important to consider how the DOCC will be transported to the operating environments.

Transportation Mission Statement

Transportation systems have been analysed for the DOCC Project so as to facilitate transportation of necessary equipment, doctors and medicine to the DOCC as and when required. Therefore, the aims and objectives for the DOCC, from a transportation point of view, is to seek for capable vehicles for both the LEO station and the Mars mission. In addition to these, the objectives should be to have it well equipped with adequate information facilities.

Taking the above objectives into account the mission statement in respect of the transportation group is as follows:

The Transportation System should

- be able to transport safely

- people (astronauts, doctors, scientists, workers, tourists)
- facilities and goods (DOCC, medical support, resupply goods)

while using

- existing transportation systems
- new technologies

to the required locations in space

- LEO stations
- Mars

Transportation Scenarios

The scenarios of the transportation system will be based on a study of existing transportation system technology as well as new and developing technology. In respect of both missions, LEO stations and Mars, the scenarios are comprised with the fundamental concept, transportation analysis, and the interrelationships of the alternative missions and payloads. The cost of the transportation is also added to the cost contents.

Chapter 7

Orbital Application

The first of the two cases to which DOCC is applied is that of a Low Earth Orbit commercial space station.

7.1 COMMERCIAL SPACE STATION

7.1.1 Introductory Scenario

It is now the year 2015, and the International Space Station project has achieved a mature configuration. Now it is being opened for commercial, private and research interests all around the world. A new international consortium, ISS Inc., has been established to manage the privatisation of the ISS, and a new space station module is being designed exclusively for ISS Inc. interests. The module will be manned by semi-professional personnel, i.e. civilians funded by ISS Inc. or its customers, with minimal space training.

There are four goals with corresponding markets for the new ISS Inc. module:

- *Scientific research: the ISS Inc. module will offer new facilities for microgravity related research. Universities and research institutions can pay to have their people conduct research personally in orbit.*
- *Commercial Research and Development: the extensive ISS Inc. facilities give companies unprecedented resources for research and development of new commercial products (e.g. new drugs, semiconductor crystals). Company personnel can have the chance to perform research on-site.*

- *Mass production of specialised products: companies can set up and run small production units to produce specialised products that could not be realised on Earth for market consumption (e.g. calibration beads for electron microscopy).*
- *International ventures: ISS Inc. offers an excellent chance for new partnerships between institutions and companies all around the world, as well as an opportunity to share costs and share discoveries in space.*

To achieve all four goals and sustain costs, the ISS Inc. module will boast a crew capacity of twenty personnel maximum; ten to twenty people will be expected to be working in space on short duration shifts, rotating with new personnel from the ground. The ISS Inc. module personnel will include two members with specialised medical training. To address concerns of human health and safety, ISS Inc. has contracted the DOCC Studies Group to develop and establish a medical facility for the ISS Inc. module, which may or may not supplement the existing ISS medical system.

7.1.2 Assumed Existing Infrastructure

Taking into account the above scenario, assumptions were derived which allowed the precise context of the use of the medical facility to be assessed. The facility would be fitted to the International Space Station where a specific commercial module has previously been added.

One major driving aspect in all space programmes is to keep costs at a reasonable level, and to this end the DOCC facility will be considered to take full advantage of the space station capabilities, including:

- Power supply
- Telecommunication system
- Thermal control

In the event that independent systems are required for other applications, such functions would become part of the DOCC.

7.1.3 Scenario Dependent Requirements

The medical facility will have a capability of up to twenty personnel, dependent on schedule. These persons will be “semi-professional” astronauts with a minimum of pre-flight training. At least two of them will be more extensively trained: one will be a doctor and the other a medic.

With this scenario being commercially oriented, the mission duration is expected to range from two to five weeks, with a typical work pattern of up to fourteen hours/day.

7.1.4 Environmental Constraints

The natural and induced environments in which the orbital station functions create boundary conditions which affect the design and operation of the medical facility. The purpose of this chapter is to highlight the critical on orbit environment, namely the neutral atmosphere, thermal considerations, ionising radiation, meteoroids and orbital debris, microgravity, and eclipse duration.

7.1.4.1 Neutral Atmosphere

The medical facility will orbit within the Earth's tenuous upper atmosphere. At the altitude of 400 km, there still exists atmospheric effects which influence the design and material selection of space vehicles. Two of the most significant aspects of this environment are :

- Atmospheric density that generates drag and orbit decay, which the altitude control system must overcome.
- Atomic oxygen which affects exposed surfaces resulting in material oxidation, material erosion and surface contamination.

Assuming that the control system of the space station is able to compensate for the extra drag caused by the medical facility, we will consider only the atomic oxygen in our application. Typically, Oxygen maximum density can reach 10^{15} atoms/m³ at solar maximum conditions for the given altitude [Larson, et al., 1991].

7.1.4.2 Thermal

The natural thermal environment experienced in orbit induces surface temperature variations, thermal stresses and influences heat rejection as well as solar array power generation efficiency. The medical facility will have to withstand a temperature range from -70°C in eclipse up to +110°C in sunlight.

7.1.4.3 Ionising Radiation

The facility will be continuously exposed to ionising radiation from two primary sources:

- The inner trapped radiation belt.
- Galactic cosmic rays.

The greatest exposure will be observed when the facility passes through the high proton flux region, known as the South Atlantic Anomaly, five to six times each twenty-four hours, accumulating 50 to 95% of its received exposure. In addition, it will also be exposed to lower levels of very high energy (up to several hundred GeV) and highly penetrating Galactic Cosmic Rays (GCR). The modulation of GCR in Low Earth Orbit (LEO) is dependent on the strength of the solar magnetic field.

The ionising radiation has sufficient energy to dislodge electrons, breaking chemical and molecular bonds and thereby affecting living organisms, chemical processes, materials and electronics.

7.1.4.4 Meteoroids and Orbital Debris

Collisions involving the medical facility and meteoroids/orbital debris will occur during its lifetime. Performance degradation of unshielded equipment may result from impacts with micron-sized particles. The upper end of the threat range would be a several centimetre projectile whose impact would be capable of causing potentially catastrophic loss of the facility and its crew.

Typically, debris velocities range from 8 to 14 km/s and meteoroids can have a velocity of about 19 km/s [Reference guide, 1995].

7.1.4.5 Microgravity and Eclipse Duration

At an altitude of 400 km, the medical facility will be functioning within a microgravity environment (10^{-6} g) and will encounter one eclipse period each orbit or about fifteen eclipse periods per day (orbit period time = 92.5 min) with a maximum shadowing time of approximately thirty-six minutes.

7.2 MEDICAL ASPECTS ON THE ORBITAL APPLICATION SCENARIO

The DOCC is designed for space environmental conditions and changes do not have to be performed to make it applicable to the orbital scenario, when considered from a medical viewpoint. However, brief remarks on factors that may have an impact on the design will be discussed below.

7.2.1 Crew Selection

Well designed selection and training programmes are crucial prerequisites for the successful completion of manned spaceflight. In the future, it will be common to stay in an orbital station up to five weeks per crew-cycle. Medical treatment by the space physician on board is limited. Crew time is very expensive so it is very costly to lose the working force of one or more crew members during a mission. When an illness is very serious, it is mandatory to evacuate the patient to Earth for treatment via a Rescue Vehicle (see Section 7.2.6).

In conclusion, it is very important to minimise the danger of illness on board the station through the proper selection of crew members. This should be conducted in accordance with the guidelines outlined in Section 1.3.

7.2.2 Physiological Countermeasures

Countermeasures in an orbital application would be applied in accordance with the directions given in Section 1.6. However, the relatively short duration (two to five weeks) of microgravity in this scenario will have some impact on countermeasure prescriptions. It will not be crucial to exercise vigorously to maintain fitness and health during this time span, although neurosensory countermeasures must be applied since most of the symptoms occur during the first week. In addition, countermeasures prior to re-entry to counteract orthostatic hypotension will be necessary.

7.2.3 Medical Monitoring for an Orbital Station

Because of the specific mission scenario for the orbital facility (time of stay: two to five weeks), the hardware necessary to monitor the physiological parameters (Table 7.1) of interest is much less than in the core module design (see Section 4.1.4).

	CV-System	Radiation	Blood-Analysis	Physical/Dental exam
Clinical Lab - Unit			CBC with differential	general health
Medical Routine Equipment	blood pressure			ENT, eye, temperature, blood pressure, skin, Neurological exam
ECG	heart rate, bioelectrical activity of the heart			general health
Radiation Monitoring		individual dose		

Table 7.1 Required Medical Hardware for the Medical Monitoring System on the Orbital Facility

The time schedule for the Medical Monitoring System on the orbital facility is also greatly influenced by the short duration mission scenario (see Table 7.2).

Exam	Frequency of exams	
	1 - 2 times	as required
limited blood-analysis (see Section 4.1.4)		X
physical/dental-exam	X	
ECG	X	

Table 7.2 Monitoring: Routine for the Orbital Facility

The radiation monitoring will then be the same as in the core module design (see Section 4.1.4).

7.2.4 Pharmaceutical Kit

For the orbital application, the amount of medication and bandages can be minimised due to the possibility of resupply. The amount of medication will depend upon the crew size, possibility of incident occurrence and drug metabolism in microgravity. The possibility of occurrence depends on the on board activities.

7.2.5 Dental Kit

The dental kit for the orbital application will be the same as the core module design, with additional supplies as necessary.

7.2.6 Rescue Vehicle

The Rescue Vehicle will be part of the LEO orbiting facility, and has to provide immediate evacuation capability for critically ill and injured crew members. Also, it must be capable of supporting the entire crew in the case of accidents or failures of the LEO orbiting facilities systems.

7.2.6.1 Medical Problems Requiring Rescue Vehicle

The following medical problems can not be treated aboard the LEO orbiting facility due to the extensive equipment required for treatment. This equipment will not be available on the orbital facility and therefore will require the Rescue Vehicle to return the crew member(s).

- Severe hypoxia
- Major burns (2nd and 3rd degree)
- Major trauma (thoracic, abdominal and neurological injuries, etc.)
- Meningitis
- Acute pancreatitis
- Septicaemia
- Cerebrovascular catastrophes
- Cardiovascular catastrophes

While the possibility of the occurrence of these medical problems is low, they are life-threatening if left untreated. The inclusion of the Rescue Vehicle should be considered for long duration manned space missions. Specifically, an analysis should be performed in order to assess the risk/cost ratio involved.

7.2.6.2 Medical Requirements for Rescue Vehicle

Basic medical requirements for the Rescue Vehicle are as follows:

1. It shall have its own on board life support system capability.
2. It shall have evacuation capability to Earth for the minimum of one incapacitated crew member and one crew medical officer, up to the entire number of crew members.
3. It shall complete the rescue mission (from evacuation decision to delivery of patients to the definitive medical care facility on the ground) within a prearranged time (approximation: twenty-four hours - discussed below), which depends on criteria such as the rescue decision time, the space station's orbit, and the landing site.
 - Preparation and waiting for deorbit opportunity = 18 hours.
 - From separation to landing = 3 hours (maximum).
 - From landing to crew recovery = 1 hour (maximum).
 - From recovery to Medical Care Facility = 2 hours (maximum).
4. It shall provide adequate transportation for patients.
 - Re-entry/Landing g-force level and direction (body axis)
 $G_x^* : \pm 2 \text{ g}$, $G_y : \pm 1 \text{ g}$, $G_z : \pm 0.5 \text{ g}$ (maximum)
* X-axis direction is through crew member's chest toward his back, which is where human body shows the maximum tolerance level for linear acceleration.
 - Vehicle rotation during re-entry
Limit of $\leq 5 \text{ rpm}$ rotational rate
(Vehicle rotations $> 5\text{-}8 \text{ rpm}$ cause nausea, disorientation)
5. It shall provide adequate accommodation of patient (seat and couch) and restraint supports.
Space required for a patient lying fully relaxed = $1.3 \times 2.5 \times 1.5 \text{ m}$
6. It shall provide communication capability for two-way voice link.
7. It shall provide the following functions:
 - airway control
 - cardiovascular support
 - monitoring of vital functions
 - homeostasis

In addition, the following items will be needed for on board functions:

- Automated ventilator
- Intensive care monitor

- Intravenous infusion pump
- Respirator
- Accommodation for lying and sitting transport
- Consumables (water, oxygen consumption, medication)

Finally, the following items will also be needed for medical ground support:

- Medical recovery teams
- Air or ground ambulances
- Fully equipped local hospitals

7.2.6.3 Design Goals for Rescue Vehicle

The Rescue Vehicle should consider the following aspects in its design:

- Highly autonomous system for re-entry and landing
- Capability of rapid ingress/separation
- Provision of ‘shirt-sleeve’ environment
- Provision of adequate transport conditions for patients
- Easy recovery

7.2.6.4 Conclusions

As mentioned above, the inclusion of the Rescue Vehicle should be considered for long duration manned space missions. Specifically, an analysis should be performed in order to assess the risk/cost ratio involved.

At present, medical data regarding the influence of g-force and reconditioning due to re-entry on critically ill and injured crew members is lacking. Medical experiments and simulations concerning the influence of re-entry on patients in a critical condition need to be made in the future.

7.2.7 Impacts on Architecture

All of the above mentioned functions of the orbital DOCC medical facility require adaptation of the core module architecture. The main architectural concerns for the orbital DOCC are the zero gravity, the capability (due to Earth proximity) for telepresence and virtual reality and the relatively short duration of the mission. Overall size and mass remain approximately the same as the core. A complete list of the core module hardware and adaptations for the orbital case are shown in Table 4.1

Table 4.8 shows a matrix of the constraints imposed on the core DOCC architecture by the medical requirements. An X in the matrix indicates either a

requirement for an electronic connection or physical proximity within the DOCC module. These relationships hold for the orbital DOCC.

7.2.8 Computerised Health Maintenance System

For the orbital application, the core module of the design for the Computer Health Maintenance System (CHMS) will be modified slightly.

For the orbital application, the time required to send a communication from the spacecraft to the ground station will be very small. Therefore, telemedicine via video conferencing will be used more extensively and the CHMS will be used more as a backup system, especially for emergency situations where communication with the ground is lost. Less data storage will be needed because it is easier to transfer data to the ground station and store the information on the ground than in space. In addition, a specialised knowledge base containing specific information regarding injuries for the orbital application should be designed. Finally, the CHMS will be designed with the capability to perform more physiological monitoring and other medical tests, as medical monitoring and testing will be a large proportion of the function of the CHMS for the orbital application.

7.3 SPACE TRANSPORTATION TO LOW EARTH ORBIT

7.3.1 Introduction

DOCC has the ability to support facilities for people living in a Low Earth Orbit space station. The space transportation technology is dedicated to the use of the space for the benefit of Earth. People living in the Low Earth Orbit space station will need different, quick, and safe space transportation systems to maintain health and support life. Therefore, this system plays a very important role in the design of the DOCC within the complete mission.

In this section, the transportation systems for the DOCC are stated briefly. The existing and future vehicles, technical requirements, cargo transportation system and crew return options are presented.

7.3.2 Existing and Future Vehicles

Amongst the very large number of space vehicles, only a few can be used to go to the Low Earth Orbit space station because of their rendezvous and de-orbiting capabilities.

The following table (Table 7.3) summarises the existing or future launchers which can provide access to, or return from, the space station. One or several of the following launching systems will be selected, depending on the type of payload which is required for the DOCC:

Vehicle	Agency	CRV Available
Space Shuttle	NASA	Partly
X-33	NASA	
Energia/Buran	RSA	
Soyuz	RSA	Permanently
Progress	RSA	
Ariane 5	ESA	
ATV	ESA	
CRV	ESA	Permanently
H2	NASDA	
ATV	NASDA	
HOPE	NASDA	

CRV: Crew Rescue Vehicle ATV: Automated Transfer Vehicle

Table 7.3 Existing and Future Launchers Capable of Space Station Support

More details regarding space transportation to LEO are given in Appendix G.

7.3.3 Technical Requirements

7.3.3.1 Spacecraft Acceleration Load Factors and Vibrations

One constraint for the design of the DOCC is the mechanical load factors experienced during launch, transfer and re-entry of the transportation system. In most cases the loads occurring during launch and re-entry of the transportation scenario are the drivers for the design of the on board systems. Depending on the scenario (manned or unmanned) different parameters and values have to be taken into account.

Table 7.4 shows the maximum g forces of the U.S. Space Transportation System, for both lateral and axial accelerations.

Launch Vehicle		Maximum Lateral ** Acceleration, g's	Maximum Axial Acceleration, g's
STS	Lift-off	±2.5	3.2
	Landing	±4.2 1.5	2.0
STS/IUS	Lift-off	±2.6	4.7
	Landing	±4.2 2.4	1.7

**Minus signs indicates tension.

Table 7.4 Maximum Axial and Lateral Acceleration During Lift-Off and Landing of the Space Transportation System

Apart from the g loads, the design of the modular and adaptable DOCC has to take into consideration the different frequencies at which the transportation systems can operate. This will have an impact on the fixing mechanisms and

The following nine points highlight some technical requirements for the evaluation of the future DSTS:

1. *Reliability*

The initial, average and inherent probability that the transportation system will transport, successfully, the DOCC.

2. *Human Safety*

The risk of loss of human life during the ground or flight operations of the transportation system during its entire life cycle.

3. *Single Flight Payload Capability*

The size (mass, volume and dimensions) of payloads for a single flight of the DOCC space transportation system, which can be accommodated under optimum conditions to all destinations, including loading and unloading of cargo and passengers.

4. *Annual Payload Capacity*

The cumulative payload capability per year ("transportation volume") of the individual space transportation system and its growth rate from the initial annual operational capability during the entire life cycle, as an indicator for "overall systems performance".

5. *Operational Flexibility (Resiliency)*

The capability of the space transportation system to adjust rapidly to unplanned events, such as mission, payload or organisational changes, technical problems, funding problems, emergencies and major accidents.

6. *System Compatibility*

The compatibility of the elements of the DOCC transportation system, in its passenger and cargo versions, with other existing or planned space transportation systems. Also, compatibility with elements for terrestrial use.

7. *Development Risk*

The relative maturity of the technologies employed in the selected elements of the DOCC transportation system, determining the confidence levels in cost, schedule and performance estimates.

8. *Cost-Effectiveness*

The economic performance of the DSTS during its life-cycle, measured in terms of annual and cumulative system acquisition and operation costs, divided by all payload masses and/or number of passengers delivered safely to LEO.

9. *System Life Expectancy*

The duration of the acquisition cycle, and even more so, the expected availability and utility of the DOCC transportation system, in terms of operational life time, as a measure for the level of "return-on-investment" to be expected.

Great care has to be taken to the select fundamental rules for the development of different concepts of space transportation systems, to enable fair comparisons of competing concepts. Such rules should not be too restrictive, since they can easily exclude promising concepts. The following rules are recommended:

- The payload capability of a specific DOCC Space Transportation System should assume a launch site on or near the Earth equator and a mean distance to LEO of 450 km and to an inclination of approximately 50°. The reference flight time will depend on the accuracy of the vehicle, but should be between ten and sixty minutes.
- The payload mass is defined as the amount of useful payload (net payload) transported to the LEO space station, or that is transferred to space operation centres, including the packaging material, which will be used for the DOCC. In the case of transportation of liquids, their containers are also considered to be part of the useful payload.
- Launch vehicle shrouds, discarded on the ascent to, or in space, are not considered to be part of the payload, but have to be taken into consideration as part of the stage mass when determining net-payload capability.
- The reference mass for people to be transported is 120 kg/person. If more luggage is allowed, this will be defined as part of the net payload of the DSTS.

Given the considerations above, it is proposed to use the Space Shuttle as the DOCC space transportation system from Earth surface to the Low Earth Orbit space station. This selection could be modified depending on the future reliability of the X-33.

7.3.6 Crew Rescue Vehicle

The DSTS has two parts. The first part is the vehicle to transport payloads and/or people from earth to the Low Earth Orbit space station. As part of the DOCC Space Transportation System, a Crew Rescue Vehicle (CRV) will need to be included. This spacecraft will be attached to the LEO space station for the express purpose of returning the crew members to Earth at any time, and as such, the crew rescue vehicle may or may not be considered part of the normal logistical operations. The vehicle or vehicles, at a minimum, must be capable of immediately supporting all of the crew members in emergency situations, major space station system failure and especially in medical emergency, as well as returning the crew to Earth in a timely manner. Multiple crew rescue vehicles additionally permit the emergency return of some crew members with medical problems without completely abandoning the space station.

Today, there are some different escape vehicles available, such as:

- Soyuz crew-transfer vehicle (Russian Space Agency)
- EV-0 / EV-1 / EV-2 (Aerospatiale-France, Lockheed-USA). More complete details are given in Appendix G
- Crew Rescue Vehicle (ESA)

The best option for a CRV at present, is the spacecraft planned by ESA under the Manned Space Transportation Program. This vehicle should be able to land at any specific point on the Earth, which in turn, means that the crew rescue vehicle should be very exactly controllable.

The vehicle will weigh 18 tons, which corresponds to the capacity of the new Ariane 5 launcher. The payload of the vehicle is planned for four astronauts and up to 1.5 tons of equipment in a 2 m³ room. Up to 400 kg may be returned to Earth. The capsule has a diameter of 5 m and is 6 m long.

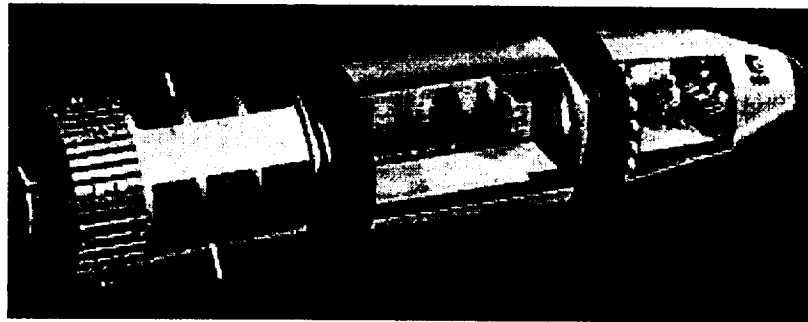


Figure 7.2 ESA Crew Rescue Vehicle

7.4 SYSTEM ARCHITECTURAL CONCEPT

7.4.1 Architectural Concept

The adaptation of the core unit presented in Chapter 4 for a Low Earth Orbit space station application is described here. The assumptions required in developing the internal form relate to how, and how often, space will be used. Three important types of function are defined; surgery or emergency treatments, minor treatments (slight burns and cuts for example) and microgravity countermeasures. The facility is laid out in a manner which reflects this division of functions, with some overlap between areas.

Figure 7.3 shows the proposed arrangement. It is assumed that standard racks will have to be used and that they will have to be arranged in a space efficient manner. Further, space must be provided to allow twenty people to perform three hours of microgravity countermeasures exercises per day. Practically, this means that four people must be able to exercise simultaneously. It was decided that they would exercise together in an area considered part of the DOCC. This requires that environmental, thermal and vibration isolation

technologies be more highly developed than they are now, by the time a commercial space station comes into operation. Otherwise, no great advances in the state-of-the-art are assumed in the design.

The DOCC, as a facility, occupies more space than that taken by its racks. A space, indicated here by a 'floor slab' is used as a countermeasures area with the exercise equipment stored in the two adjacent racks.

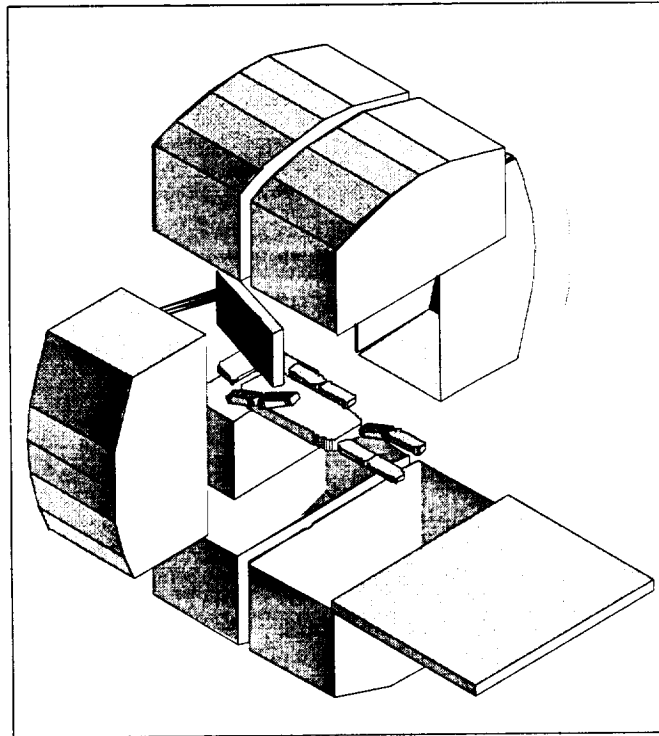


Figure 7.3 The Proposed Orbital DOCC Configuration

Figure 7.4 shows an exploded and labelled view of the DOCC racking. Equipment is stored as follows:

1. Medical computer system and monitors: half of the hardware contained in the rack is described in Chapter 4
2. Bulk storage
3. Lighting: the remainder of the core hardware
4. The bed/chair described in Chapter 4 and its associated monitoring equipment
5. Countermeasure devices and condition monitoring equipment for two people
6. As rack 5
7. The countermeasures area: this has no racks and is used to set up the exercise machines stored in racks 5 and 6

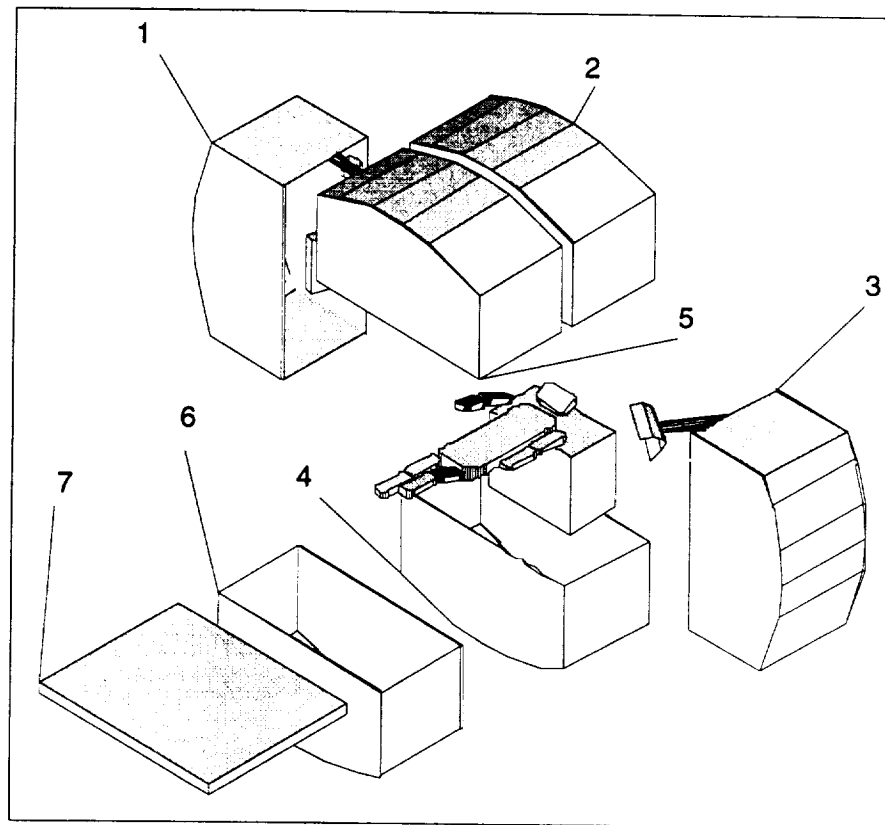


Figure 7.4 Exploded View of the Orbital DOCC Facility

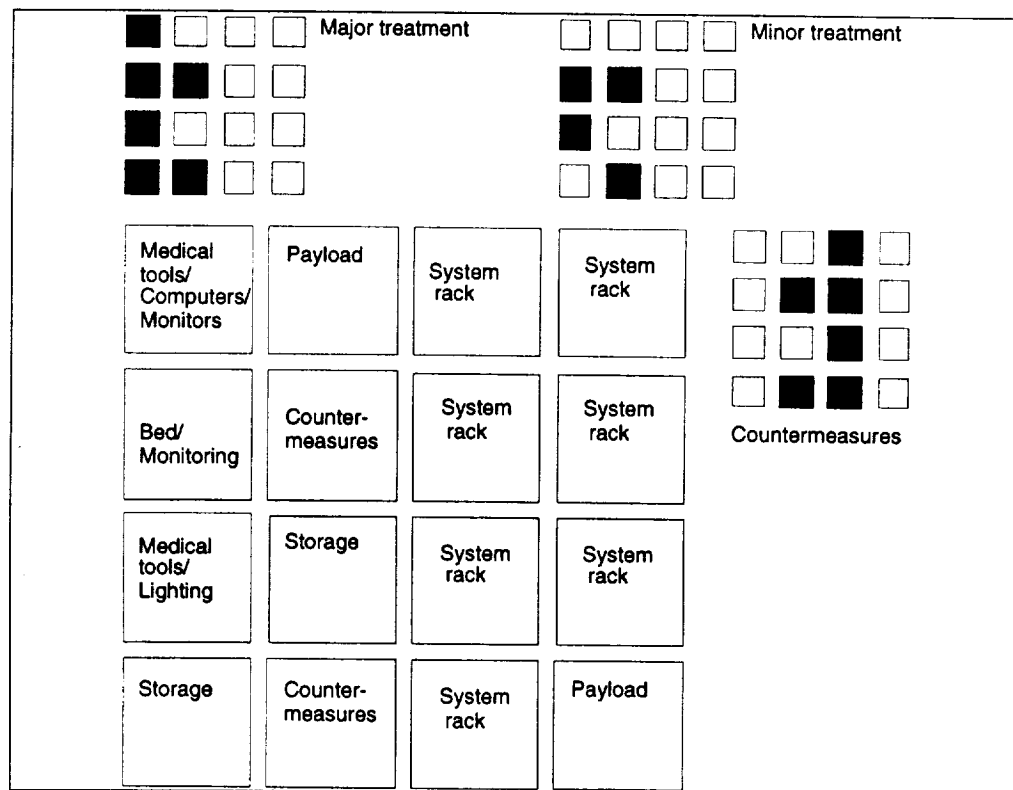


Figure 7.5 Use of the DOCC Volume for a LEO Space Station Application

The module is to be configured for a number of functions as described above. The arrangement of the DOCC, in terms of the families of functions described in Chapter 4 and how they might fit a standard space station module, is shown in Figure 7.5.

The use of the different elements of the DOCC to form these functional areas is described below.

7.4.1.1 Surgery and Intensive Care

In the event that surgery is required, the necessary racks are screened off to form a sealed area where sterile conditions can be maintained. Figure 7.6 shows the area which will be used.

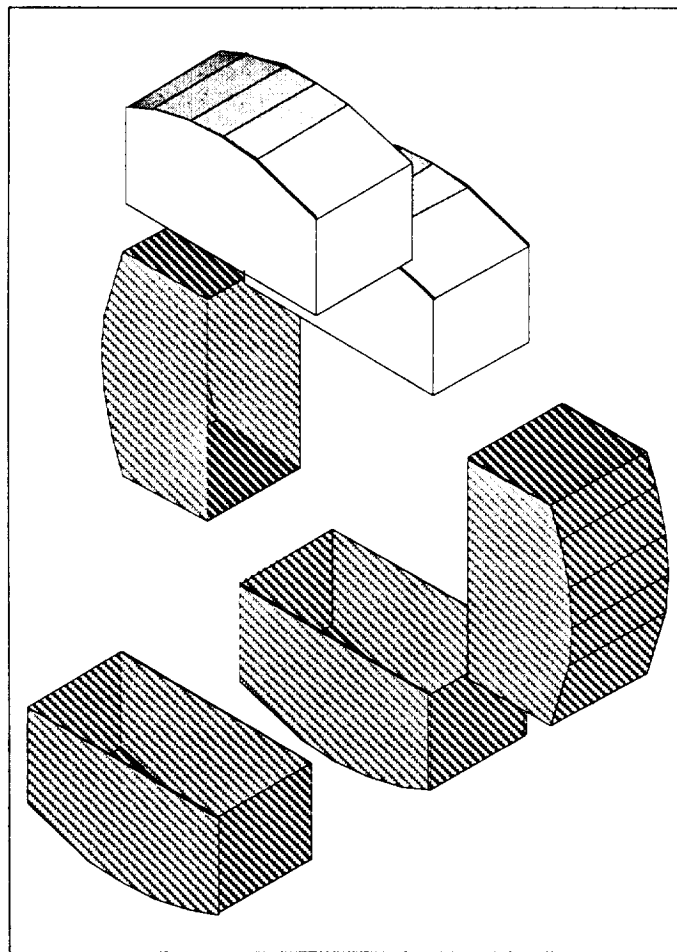


Figure 7.6 Sterile Surgical Racks (shown hatched)

Within this surgical area the bed is turned to lie lengthwise in the module and the equipment for the operation, including lights and monitors, is taken from the racks at the end of the DOCC. A patient who needs intensive care treatment can be accommodated using the racks shown in Figure 7.7.

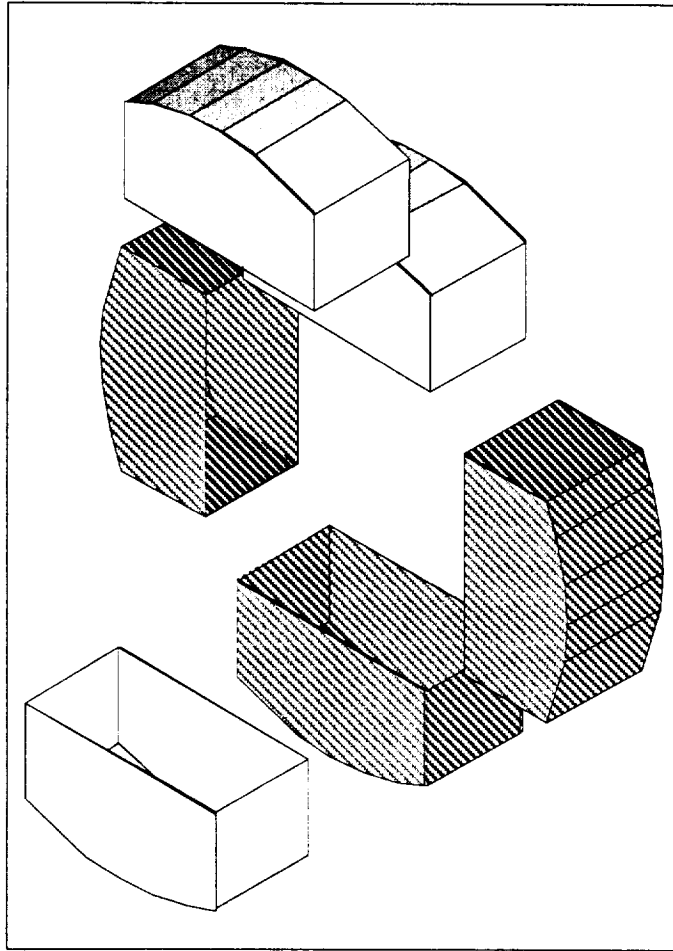


Figure 7.7 Intensive Care Racks

It is not intended that the whole area shown would be sealed off to provide an enclosed volume for the patient. Instead the bed is turned to lie across the module and is covered with a 'cloche' which provides a sealed environment which can be carefully controlled without stopping traffic through the module. This arrangement is slightly cramped, but does allow someone to be kept alive until they can be moved to another treatment centre.

7.4.1.2 Minor Diagnosis and Treatment

It is intended that under normal circumstances, minor problems will be dealt within the surgical area with the bed available for the patient should it be required. If a patient is occupying the intensive care area, then these minor procedures can be conducted in the outer zone of the DOCC.

7.4.1.3 Countermeasures

Countermeasure condition monitoring equipment is stored in the racks shown in Figure 7.8. The layout is intended to allow four crew members to exercise and be monitored simultaneously. The exercise equipment is taken from storage and placed in the area at the end of the DOCC, as indicated in Figure

7.8. For a crew of twenty, this area will be in use fifteen hours per day so that equipment will not be packed and unpacked very often.

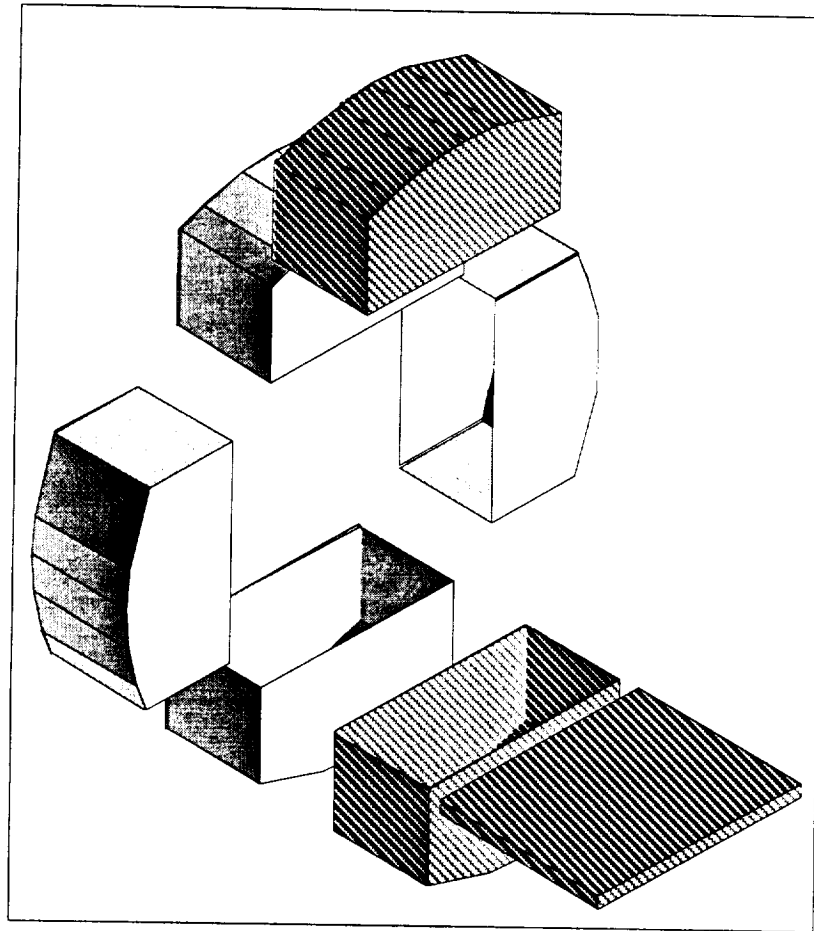


Figure 7.8 Countermeasures Racks

7.4.2 Virtual Reality Facility

The virtual reality facility in the orbital station DOCC will be the most basic VRF design in the core DOCC. Please refer to the Martian Scenario VRF description (Section 8.4.3) and the medical support virtual reality applications (Section 4.1.6) for more complete information on the VRF and its uses. The orbital station VRF will enhance the exercise countermeasures to the microgravity environment for the crew by providing a more enjoyable way to exercise in simulated environments and games. It will also provide medical support in the unlikely event that an emergency surgical procedure is required for which the on board physicians are not adequately trained. Additionally, it will allow psychological assessment of crewmembers who appear mentally compromised.

Finally, the VRF will provide the ability for crew members to privately communicate with people on Earth in real-time virtual environments. In spite of these uses, the VRF is not considered as an essential facility for the orbital station as it is for longer duration scenarios, because it does not significantly

enhance the chances of mission success in short-duration missions which remain in Earth orbit. It is still appropriate to include a VRF in the orbital station DOCC however, because the semi-professional crew in the described scenario are more likely to require the medical, recreational, and psychological support which the VRF provides than would fully professional crews in a similar mission scenario. For example, an instance of mental impairment is considered a relatively likely occurrence on the orbital station, as crew members may not have been as rigorously screened for mental stability and have not been as well trained for the psychological challenges of spaceflight. A crew member could be screened privately by personnel on Earth using the VRF.

7.5 ADAPTATION TO CORE DESIGN

7.5.1 Modifications to Core Operations

7.5.1.1 User Selection and Training

Users will be selected according to criteria for short duration missions, hence they will be selected on individual merit, using “select-out” medical criteria as detailed in Section 6.1.1. They will then be trained at the Basic Crew level as defined in Section 6.1.2.1. Higher levels of user training will not be required, as two teams of dedicated personnel will be assigned to the facility for three month shifts. Each team will consist of one person with Specialist-level training and one person with Medic-level training.

7.5.1.2 DOCC Facility Start-up

Initial Supply - Due to the ability of the DOCC to be resupplied during Earth orbiting missions, the initial supply of the ISS DOCC will utilise the minimum medical resources needed until the next resupply shipment. This initial supply will be weighed as the most conservative need versus the allowable weight, storage, perishable concerns, and the time between resupply.

Test Verification - The testing and reliability of the remote medical facility will vary depending upon the ability to resupply spare parts. The ISS scenario will allow frequent resupply of spare parts and hardware. As a result, the system may be designed in a more modular fashion to allow line-replaceable units to be removed and replaced as necessary. The testing of these subsystem components may be performed at the vendor with only minimal interface testing required prior to launch.

7.5.1.3 Procedures and Protocols

The discussion in Section 6.2.1, considers how medical procedures and protocols in the Flight Data File could be converted to hypermedia format and accessed through a notebook computer or other mobile computer. This system will be called a Mobile Hypermedia Flight Data File (MHFDF). This computer could also be linked to the DOCC medical facility through

dedicated network ports or a wireless network and from there to the GCC to allow for the exchange of information and applications as required. The MHFDF will be portable within the medical facility and to the site of an emergency within the station, although not into the air lock.

This solution is attractive for the commercial ISS application because it will have a low development risk and it will be easily upgradable as technology improves, both in terms of the hypermedia procedure files and the hardware. Paper manual versions of the flight procedures will also be provided as a backup solution.

There will obviously be some modification in the specific procedures and protocols themselves due to the microgravity environment and the possibility of crew return in an emergency.

7.5.1.4 Maintenance and Logistics

In the orbital mission, logistics is available in certain intervals. On orbit storage is minimised and most resupply items are stored on the ground, except for time critical items (see Section 6.2.2, including Tables 6.4 and 6.5).

7.5.1.5 User Deconditioning

Due to the length of the mission, the user deconditioning period will be short: on the order of five to ten days. Emphasis will be placed on short term exposure to microgravity effects and the effects of acute stress, as these are the most important deconditioning issues for the short term.

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Chapter 8

Mars Application

8.1 MARS SCENARIO

8.1.1 Introductory Scenario

To follow-up on the first preliminary manned and unmanned expeditions to Mars, an international mission to establish the first permanently operated base on Mars is being prepared for the year 2020 under the International Mars Mission (IMM) initiative. The Mars base will have a maximum capability for six crew members.

The objectives of the missions are to:

- *conduct scientific investigation on Mars, that will include surface reconnaissance and geology;*
- *perform viable resource management to exploit local resources for a self-sustaining base;*
- *present another inspirational precedent in successful international collaboration.*

Fresh from their success with ISS Inc., the DOCC Study Group has been contracted by the IMM to design a medical facility for the space transport vehicle and the Mars base. It is expected that the first crew will consist of six astronauts, who are expected to perform base construction operations on the Martian surface.

According to the International Mars Mission the manned part of sending humans to Mars is divided in two phases: initially a short duration stay, followed later by a stay of longer duration. At the proposed time, the first phase is assumed to have taken place. During the first visit to Mars humans spend forty days on the Mars surface setting up facilities in preparation for the next manned mission. The second phase of the mission is to be a long duration stay at the same site as the previous mission. It is planned that the astronauts will stay for a longer time, four hundred days, and conduct a range of scientific and technological work.

8.1.2 Assumed Existing Infrastructure

As mentioned above a manned mission to Mars has already taken place. Their task was to set up facilities on the Martian surface in preparation for a stay of four hundred days. A habitation module will have been set up for living and working purposes. It will have been designed with modularity, versatility and expandability in mind ensuring easy reconfiguration and multipurpose functionality. Attached to it will be a safe haven, mainly for radiation protection. In preparing for a permanent Mars base there will also be processing and power plants. A rover will be ready to use. Additionally, a communication system and a launch pad will be ready for use.

Due to the long travel time of transfer and uncertainties in how microgravity affects the human body for such extended time as well as to the necessity to have a crew that is healthy and strong enough to perform work on arrival at Mars, the transfer has been chosen to be in artificial gravity. By rotating the transfer vehicle, an artificial gravity effect (0.38 g) is to be achieved.

8.1.3 Scenario Dependent Requirements

The stay on Mars is planned for four hundred days. The transfer of the crew to Mars and back takes approximately seven hundred days. This gives a total of almost three years for the crew to be away from Earth.

The crew will consist of six professional astronauts including two medical specialists and four medics (Chapter 6.1.2). They will be highly experienced individuals with years of pre-flight and orbital training. Being on an international mission, the astronauts will represent a wide variety of national and cultural backgrounds. It is also anticipated that the crew will be slightly older than usual (forty years old) in order to reduce the impacts of radiation. Older people have a lower risk of developing cancer due to radiation than younger people exposed to the same dose, because older people have shorter life span.

8.1.4 Environmental Constraints

The physical environment of Mars will provide some of the requirements for the design and implementation of the DOCC medical facility. It is therefore

necessary to take a closer look at the environment encountered on the Martian surface.

- Mars is a smaller planet when compare to Earth. Its diameter is about half of the Earth's diameter, and the gravity on the Martian surface is 0.38 g.
- Mars lacks a magnetic field.
- Radiation level will depend on solar activity, especially in the absence of a magnetic field. NASA's safe operating dosage for professional astronauts is 62 rem/year.
- On the Mars surface, the average temperature is -63 °C with a maximum of 20 °C and a minimum of -140 °C.
- The atmosphere on Mars is very thin containing mainly carbon dioxide and small amounts of nitrogen, argon and traces of oxygen and water.
- The average surface atmospheric pressure varies on a semi-annual basis and is 1% of the Earth's. The atmosphere is however thick enough to support strong winds and vast dust storms.
- In communicating between Mars and Earth there will be a considerable delay. Depending on the relative positions of the two planets the delay will be between two and forty minutes. There will also be occasions when communication will not be possible at all due to the interference of the Sun.
- During transfer to Mars, space debris, atomic oxygen in Earth orbit and micrometeorite environment must be taken into account.

8.2 MEDICAL REQUIREMENTS FOR THE MARS MISSION

Unique medical problems are encountered on a mission to Mars. Although the crew for the Mars mission will be extremely well selected, the long duration and environmental effects will become more significant than for near-Earth missions. Besides the problem of cardiovascular and musculoskeletal deconditioning, one of the biggest threats of this kind of mission is radiation. Special care has to be taken to prevent, monitor and treat radiation induced effects. Because of the long duration and the autonomous character of the mission, it is necessary to adapt some key elements of the core DOCC facility to this specific mission scenario.

8.2.1 Crew Selection

Especially for such a remote mission like the one to Mars, it is mandatory to send only people with the best medical health and the lowest risk of getting ill during the mission. It is nearly impossible to evacuate an impaired crew member during the flight or on Mars. During a Mars mission there will be a medical specialist and a medic on board but it will be even hard for them to

treat a patient properly because of limited equipment and space. Also operations in microgravity are very difficult.

Radiation exposure is identified as the major career-limitation factor for astronauts during a Mars mission, so it is essential to ascertain the amount of radiation every astronaut was exposed to during his or her life so far.

Career-limit: $200 + 7.5 \times (\text{age}-30)$ rem ... for males
 $200 + 7.5 \times (\text{age}-38)$ rem ... for females

Maximal career-limit: 400 rem. This equals to 3% increase in future cancer risk. Annual limit is 50 rem [Barett, NASA 1996].

8.2.2 Physiological Countermeasure Considerations On The Mars Mission Scenario

During a future mission to Mars, which may take as long as two to three years, prevention of physiological deconditioning carries a high priority. Not only must small and potentially harmful effects be avoided to allow the crew re-entry back to Earth, but the continued and long-term presence of such changes in space may induce other medical problems, which are yet unobserved [Sandler, et al. 1995].

The requirements associated with providing health care in the remote and hazardous environment of space often conflict with the mass, volume and power constraints of the spacecraft and the limitations of crew training. Also, the costs of allocating resources for health care must be weighed against the risk of medical events occurring during space flight [Billica, et al. 1996].

Two hours or more of daily exercise presently used during long duration space flight presents extreme cost to operations and drains life support materials which are expensive to place and maintain in orbit. For instance, average daily metabolic costs of 1450 kcal for exercise during Russian missions represent about half of the total energy intake of these missions. This issue will become more critical in a Mars mission [Convertino, Sandler 1995].

It does not appear that the countermeasures at the moment are completely effective in maintaining cardiovascular, neuromuscular and musculoskeletal functions. Future in-flight exercise programs and devices will probably require:

- Countermeasure exercise programs which minimise the use of crew work time and life-support resources (oxygen, water and food);
- A mix of dynamic and resistance exercise to maintain cardiovascular and musculoskeletal structure and functions, and to preserve work capacity;
- New countermeasure devices that would allow research to quantify the specificity and the amount of exercise;

- New countermeasure devices that allow both fitness monitoring and training;
- New countermeasure devices that allow simultaneous training of all extremities to minimise the crew work time.

However for a flight duration of fourteen months, the weightless environment using common countermeasures for the crew has been shown to be acceptable.

8.2.2.1 Biological Damages of Radiation Exposure

Radiation hazards exist both in Earth orbit and on Lunar and planetary surfaces and consist mainly of Solar Energetic Particles (SEP) and of the protons and Highly Charged energetic Particles (HCP) of Galactic Cosmic Rays (GCR). Consideration of biological damages due to radiation is of special importance when considering long-term interplanetary missions.

The approach to protecting crews from these damages has emphasised the development of detectors, early warning systems and shielding, or the provision of “safe havens”. The most critical part concerning radiation hazards in our different scenarios is the voyage to Mars where the crew will be rather unprotected (if limited habitat shielding or protecting magnetosphere) for a long time in an hostile environment as seen from a radiation exposure viewpoint.

The biological damages induced by radiation can be split into early, and delayed or late effects.

- Early effects:
Symptoms that become manifest from within minutes to thirty to sixty days subsequent to exposure are classified as early effects. For early effects the biologically plausible hypothesis seem to be that the severity of tissue response will depend on the fraction of constituent cells having been killed and the tissue’s intrinsic capacity to regenerate this fractional cell loss [Silini 1983, Langham 1967].
- Late effects:
DNA damage resulting from radiation exposure is considered the most critical cause of biological after-effects by affecting the efficiency and/or accuracy of DNA repair mechanisms or the production of DNA precursors. These kind of damages can induce progression of mutations to benign or malignant tumours.

It is interesting to notice that the level of damage implied by a specific radiation dose is dependent on environmental stress factors [Langham 1967]. For example, radiation and microgravity stress have a synergistic effect, through which damage from radiation exposure becomes more severe in microgravity.

8.2.2.2 Biological Damages of Radiation Exposure Countermeasures

The following is a record of the pharmaceutical countermeasures that attenuate the damages induced by radiation. Physical shelters will not be dealt with.

Three main groups of pharmacological agents have proven to provide some degree of radioprotection [Giambarresi, Walker 1989]:

- Aminothiols
- Antioxidants
- Eicosanoids

Figure 8.1 shows the possible sites of action of these drugs indicating that they exert their effects by either providing protection or repairing damage.

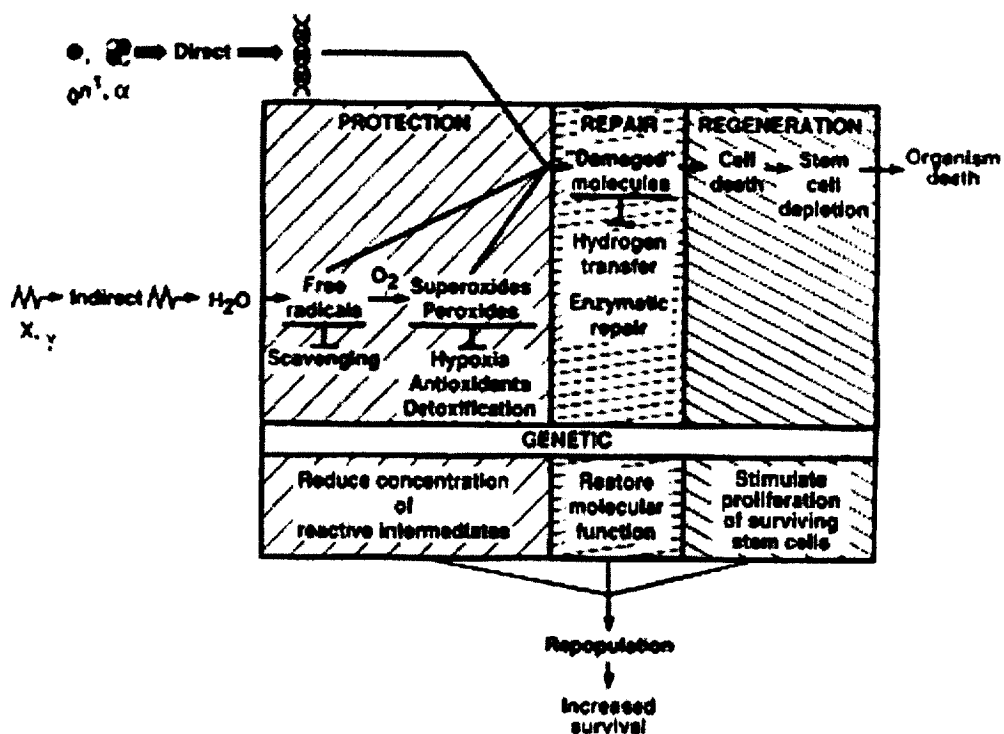


Figure 8.1 Schematic Picture Showing Possible Sites and Mechanisms of Action of Radioprotectants [Giambarresi, Walker 1989]

Diminished *oxygen concentration* reduces the damage and mortality of essentially all cell types which have been studied including micro-organisms and plant and tumour cells, while increased oxygen levels exaggerate radiation toxicity [Gray 1953]. Of course, severe hypoxic conditions are not recommended, but additive or potentiating effects of some other radioprotective or radiotherapeutic agents could be important when aiming at minimising the damage during increases in radiation exposure.

The above mentioned agents or conditions must be used before radiation exposure. Far less is known of radiotherapeutic agents that can be used after radiation exposure. However, there are some substances that might be used, with good results, after radiation exposure. Since one of the frequent consequences of irradiation is severe infection, treatment with *antibiotics* and other supportive therapy such as *fluid* and *platelets* is often effective if the exposure is low.

A hormone that seems to have beneficial properties is *erythropoietin*. In animal studies, survival almost doubled when erythropoietin was injected after irradiation [Nardu, Reddi 1967]. Different *cytokines* have also been proposed to be effective radioprotectants by stimulating regeneration in a damaged cell population. Bone marrow transplantation could also be an option to restore a damaged blood stem cell population.

In general, radiotherapeutic strategies aim to increase survival by stimulating the regeneration and function of stem cell populations which were affected by radiation induced cell death.

8.2.3 Pharmaceutical Kit

For the Mars application the core module design for the pharmaceutical kit should be extended.

Since fractures are more likely to occur during the Mars mission, the bandages kit should be more extensively equipped in amount and diversity. For instance, one should consider including casting capabilities in the bandages kit to support fractures.

Another important point to consider is the shelf life of the medications which should last at least as long as the mission duration or at least until the next re-supply. The capability of producing injection-grade fluid from potable water would help to enhance the storage duration of short shelf life intravenous fluids.

In case of an acute radiation exposure, which is more likely to occur on the way to and on Mars, a bone marrow transplantation by re-injecting the crew member's own bone marrow may be necessary. Therefore, a small amount of bone marrow of each crew member may need to be stored in a radiation shielded, nitrogen cooled, freezer at -196 °C. Also special radiation protective drugs and specific stimulating factors to enhance blood cells and their precursors to proliferate are necessary (see also Chapter 8.2.2).

Blood storage: (see also Chapter 4.1.2) The blood should be stored in the same freezer mentioned above.

8.2.4 Dental Kit

The equipment part of the dental kit is the same as in the core module, however the amount of supplies in the consumable part must be increased to be sufficient for the whole Mars mission.

8.2.5 Medical Monitoring For A Mars Mission

Because of the long duration of the mission and because of the special environmental conditions (transfer phase from Earth to Mars and the stay at the surface) it is necessary to use everything that is described in the core module (Chapter 4.1.4). In addition to that, there is a need for a more thorough medical monitoring with respect to radiation especially during the transfer phase, and with respect to the dust environment on the surface of Mars (Table 8.1).

	Mars-Transfer	Mars-Surface
Radiation	specific screening ² DNA-test ³	specific screening ² DNA-test ³
Dust		ENT and eye (foreign objects) ¹ , airway obstruction ¹ , lung function ¹

1: weekly, 2: monthly, 3: every third month

Table 8.1 Special Monitoring Requirements for the Mars Mission

It is necessary to use additional equipment - a spirometer - to measure lung capacity and, to a certain degree, airway obstruction.

8.2.6 Impacts on Architecture

All of the above mentioned functions of the Mars DOCC medical facility require adaptations to the core module architecture. The main architectural concerns for the Mars DOCC are the gravity (artificial gravity in transfer and Mars gravity on the surface), and the increased storage requirements in the module. Overall size and mass remain approximately the same, but may increase slightly due to the need for more supplies and added hardware. A complete list of the core module hardware can be found in Table 4.1 that outlines adaptations for Mars.

Table 4.8 shows a matrix of the constraints imposed on the core DOCC architecture by the medical requirements. An (X) in the matrix indicates either a requirement for electronic connection or physical proximity within the DOCC module. These constraints remain the same for the Mars DOCC.

In conclusion, the additional demands of a Mars mission and differences in gravity, trip duration, and scientific interest have significant impacts on the architecture and design of the Mars DOCC. Greater autonomy, increased

storage capacity, and more redundancy are required since Earth rescue is not feasible.

8.2.7 Computerised Health Maintenance System

For the Mars application, the core module design for the Computer Health Maintenance System (CHMS) should be extended.

The main difference between the Mars application and other scenarios is that the latency time for communication on the Mars application will be from four to twenty minutes in each direction. However, most medical emergencies require immediate attention (e.g. myocardial infarction, large haemorrhage). Therefore, the computer system should be well equipped to provide quick and reliable information for such emergency procedures. In addition, the medical officer may be involved in the emergency, so the information will have to be put into a format which is easily understandable in chaotic situations (e.g. step by step photos of the procedure to follow for intubation).

In addition, different injuries are likely to occur during the Mars mission compared to those in other scenarios (e.g. excessive radiation exposure and dermatitis due to Mars dust). Therefore, the computer will have to be programmed with this specialised information.

It is also possible that current medical information will change between the time that the mission begins to the time that it ends because the mission duration will be substantially longer. Therefore, the computer system will have to be robust and the personnel involved with the mission must have the ability to alter the medical knowledge base. It will also be important for the computer system to retrain medical personnel with this new knowledge. The computer system should also be used as a tool to review critical emergency information so that the crew is always ready to handle any medical emergency.

8.2.8 Virtual Reality for Medical Training on Mars

Time delay for telemedicine on Mars plays an important role. Therefore only elective and non emergencies medical events would benefit from this new technology. Therefore, the Virtual Reality system would be used mainly for retraining and continuing education for the space doctor.

Studies have shown that for a wide range of diagnostic and therapeutic procedures, physicians performing their first cases are much more likely to make errors than experienced practitioners. This is also true regarding physicians who do not perform procedure for a long time. Space physicians on the DOCC will find a great use in keeping their current sharpen, smooth and fast operations, if they will regularly simulate medical procedure under VR environment. Virtual reality allows physicians to perform hundreds of practice operations without causing any harm to their patients. Mistakes can be immediately rectified without any harm to the patient. When a mistake is

made, the computer can indicate that a mistake was made, and the correct procedure can be shown to the physician. In the event that the physician does not have information regarding a procedure, the information can be requested from the ground station and the data may be sent immediately.

In the event that the ground station does not have information on the event, artificial intelligence may be used in conjunction to the VR system to predict how the environment may change and change its simulation. For example, if surgery must be done in a microgravity environment, and the ground station has no information available on microgravity surgery, an artificial intelligence program can be constructed with the basic principles of microgravity. The artificial intelligence program can then be programmed to simulate the characteristics of anatomy in a microgravity environment. These basic principles can then be combined with the existing VR surgery applications to allow the surgeon to practice surgery in a microgravity environment.

In conclusion, VR may be programmed with many different types of operations that may have to be performed in the space environment. These training operations can be practised several times before the operation is performed.

8.3 TRANSPORTATION TO MARS

The information mentioned below is mainly based on a study called "International Mars Mission" performed by "The International Space University" during the summer session of 1991 [ISU design project report, 1991].

The main purpose of this paragraph is to give an overview of the transportation issues presented in this study. Subjects that will be covered are: the mission, propulsion systems, the vehicle concept and volume and mass requirements.

8.3.1 Mission Description

The mission is divided into two parts. The cargo mission will begin approximately two years before the first piloted mission. It will contain six landers; four automated cargo landers and the two crew lander/ascent vehicles. The transfer vehicle will spiral into Low Martian Orbit (LMO) and drop the cargo landers to the surface with the habitats and the equipment. When ground systems check out, the cargo vehicle will spiral out to High Martian Orbit (HMO) and wait for the crew transfer vehicle to arrive.

Two years later, the crew transfer vehicle will arrive after an outbound flight of about three hundred days, spiral into HMO, and rendezvous with the cargo transfer vehicle. Crew and DOCC equipment will be transferred to the descent/ascent vehicles. After the Hohmann transfer to LMO, the landers will descend to the Martian surface and stay there for forty days.

While the crew is on the surface, the transfer vehicle will spiral down to LMO. The crew will ascend to LMO again taking the DOCC with them, dock with the transfer vehicle and spiral out. It will then take forty days to escape to heliocentric trajectory toward the Earth. The total inbound flight duration is about four hundred thirty days. The four-hundred-day long stay mission will follow two years later and will not require a cargo mission because the crew lander/ascent vehicles will accompany it. Outbound and inbound flight durations are the same as for the forty-day flight.

8.3.2 Propulsion System

The propulsion system used is Nuclear Electric Propulsion (NEP). It was selected on basis of propulsive capability, ability to allow artificial gravity during the interplanetary transfers, and the cost and risk of developing the technology. In addition, NEP offers the potential for the rescue of the Mars Transfer Vehicle (MTV).

The specific impulses range from five hundred to two thousand seconds. Adding mass to the transfer vehicle will cause penalty to the initial mass in LEO which can be understood from the rocket equation. The ratio of initial mass over final mass (m_i/m_f) is ranged from about 1.5 to 7 depending on the specific impulse. This calculation is based on a complete reuse of the MTV (see Chapter 8.3.3).

8.3.3 Vehicle Configuration

Artificial gravity was chosen as one of the design requirements. This is also contributed to the selection of NEP, since it was possible to design a vehicle which could rotate and provide artificial gravity while it was thrusting. The gravity is 0.38 g just like on Mars. The NEP vehicle design was sized so that the total vehicle could be returned to Earth orbit, for the possible reuse of the vehicle. This resulted in a very large configuration. A picture of the configuration is included in Figure 8.2.

In Figure 8.3, the volume requirements on a per person base are shown for different missions from the past [MSFC technical study team, 1991]. The data for the Mars mission are extrapolated from these data. The volume a person needs for the long duration mission is about hundred cubic meters.

For a crew size of six, the total volume needed is six hundred cubic meters. This makes up the rough dimension of the habitat. In the IMM study the crew contained of eight people and a total volume of eight hundred cubic meters.

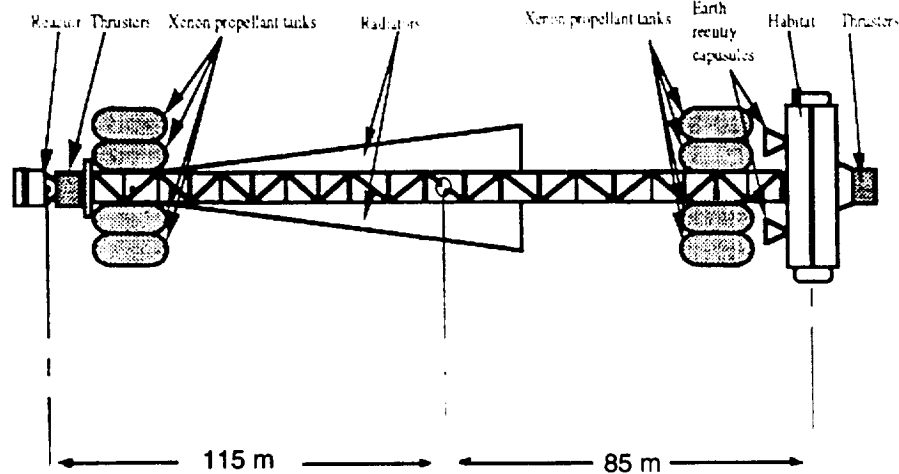


Figure 8.2 Mars Transfer Vehicle Based on NEP

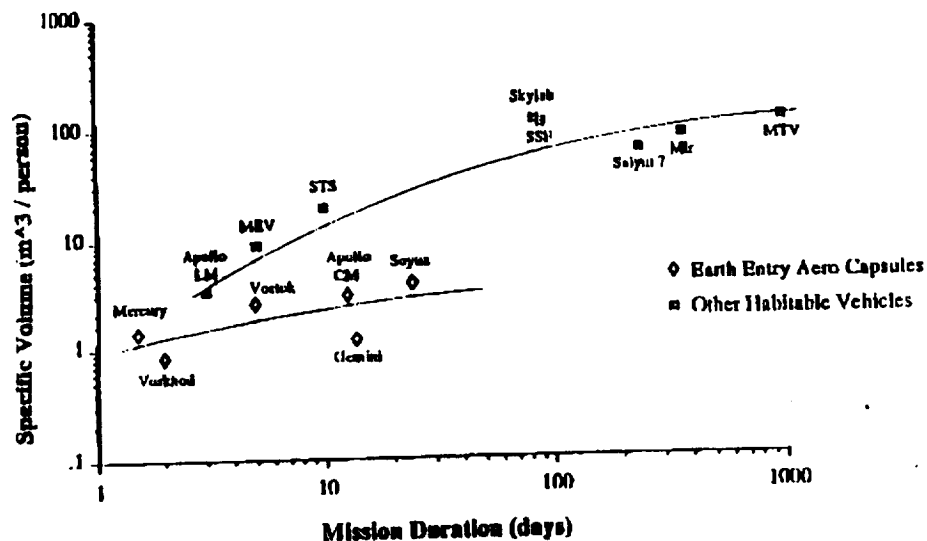


Figure 8.3 Volume Requirements per Person for Long Duration Flights

The habitat consists of two cylinders and can be a shorter version of the habitat with cylinder diameters of five meters and a length of twenty three meters designed in the IMM study. The new length would be eighteen meters based on the required volume. An example map of the living module and the working module based on eight crew members can be found in Figure 8.4. For the DOCC, the spaces reserved for exercising and health maintenance are of main interest.

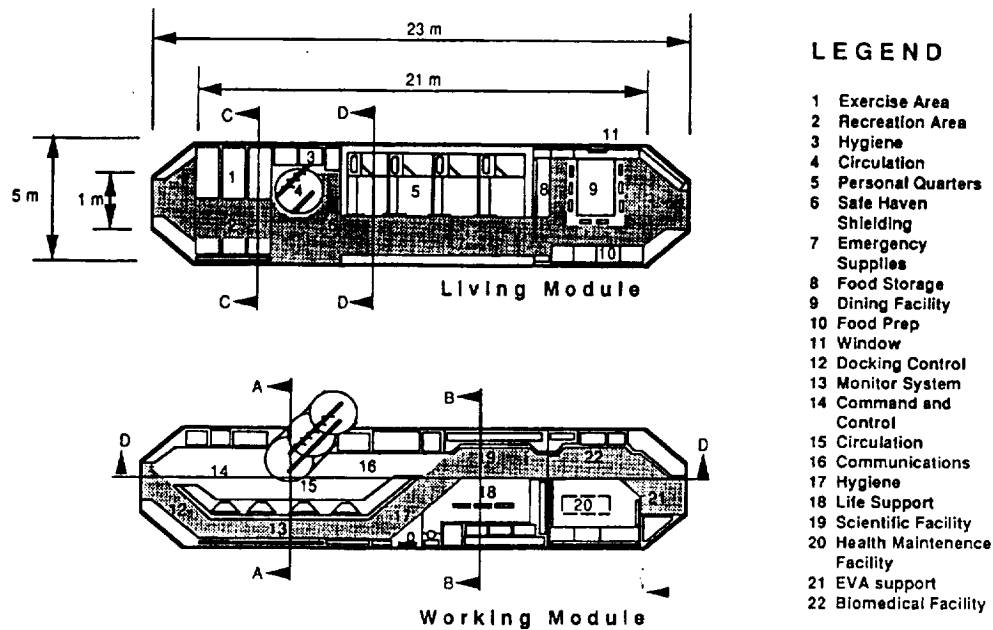


Figure 8.4 Scheme of the Living and the Working Module of the Habitat of the Transfer Vehicle.

8.3.4 Requirements on Volume and Mass

The volume requirements are split up in volumes for performing the exercise and providing the medical care, and in volumes for the actual hardware related to that. Since the data are based on eight crew members, the volume and the mass need to be downscaled. The best effort right now is to downscale these by a factor according to the ratio of the crew sizes, which means multiplying by a factor of six eighths. This is not correct, because not every piece of hardware and consumable can be downscaled if you reduce the crew. For example you would still need one bed if the crew exists of six. On the other hand, there are examples where the downscaling rules can be applied to drugs and to blood plasma. This means that superior and lower limits can be defined.

The volume of the exercise area is between 11.5 and 15 cubic meters (see Figure 8.5) and is meant for performing the countermeasures to physical deconditioning for both partial and microgravity.

The volume needed to perform the medical care is estimated to be between 7.5 and 10 cubic meters (see Figure 8.5) and is meant for providing medical care to the crew in transit to Mars and the return to Earth.

The total hardware mass is estimated to be in-between three and four tons. The storage-volume of all the hardware is 37.5 up to 50 cubic meters.

8.4 ARCHITECTURAL CONCEPT

This subchapter shall give an outline on the physical design of the medical care centre and its integration into the whole space facility for both the Martian transfer vehicle and the Martian surface habitat. The arrangement and allocation of the medical hardware and considerations on the distribution of internal space is also part of the design and will be described.

For both mission phases the number of crew will be the same (six people), as well as the duration of one way transfer and the stay on the surface will be of roughly the same duration. Finally partial gravity (artificial, 0.38 g) will be applied on the transfer vehicle. Therefore, the medical requirements are so similar, that there will be just one design applied for both mission segments (transfer and surface habitat).

8.4.1 General Design Considerations

A) Overall Mission Considerations - more than puzzling medical hardware

System design and architecture means the overall physical design of the medical facility and integration into the whole space station or habitat, going beyond puzzling the single hardware components into pre-defined space racks. This approach comprises overall mission considerations for instance to use parts of the medical facilities or their space for other purposes such as a silent recreational area, a private Earth communication centre or a virtual reality (VR) area for recreation or crew training for difficult mission operations. This results in design concepts.

B) Mission Impact - Mission Risk VS. Medical Risk

Every mission has an impact on the design of the medical facility. There is a trade-off between the medical risk to the overall mission risk, on which factors such as mission duration, number of crew members, free space radiation vs. Earth's orbit radiation level, possibility for re-supply of drugs and spare parts etc. and emergency rescue capabilities have a major impact. This impact is sketched below in Figure 8.5. One important consideration is that the medical facilities are part of the total set of hardware and total system design, and can not be treated independently for themselves.

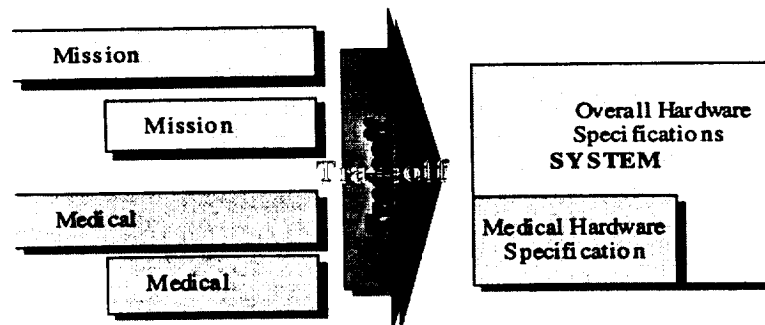


Figure 8.5 Mission vs. Medical Requirements and Risks

C) Psychological Implications

Mars mission duration will be around two to three years primarily depending on the Earth-Mars constellation, orbital trajectory, propulsion technology and planned duration on the surface. Aside from maintaining the human physiology -the “number one problem” of long duration spaceflight, psychological maintenance becomes the second highest priority, just close behind. Therefore psychological considerations are crucial to maintain human performance (see Chapter 1.2).

D) More Stylistic Flexibility and Freedom

As a consequence, the human-machine interface shall be major focus of discussion, whereas the whole spacecraft or Mars habitat are just “the machine.” This means leaving the straight-lined engineering-like internal architecture based on modular racks somewhat behind, moving towards more stylistic flexibility and freedom in the internal or even overall physical design of “the machine”, also making use of perceptual tricks, and taking into consideration sociological implications of certain design-concepts (e.g. common training areas). This normally implies less efficient use of internal space. Therefore it is a trade-off between human comfort and meeting humans psychological demands on the one hand, and efficient use of space on the other hand, which both are important factors to meet mission aims successfully. Therefore the trade-off between crew comfort and efficient use of internal space is the first, crew comfort.

8.4.1.1 Major Design Inputs

In case of the Mars application of the DOCC the following inputs were considered for the physical design.

- Medical functional requirements
- Countermeasure requirements
- Private space for psychological monitoring and treatment
- Private recreation and communication area
- Virtual reality (VR) area to combine VR with physical activities

Although all of the three first points could be referred to as medical requirements, points two and as three represent functions which have a different level of total average time required for being performed and different levels of priority. Therefore they are treated separately. The considerations concerning priority and average usage time are outlined a few paragraphs below.

The above list is probably to be detailed further as soon as a concrete mission is designed, knowing which functions have to be fulfilled for the mission. The overall design has to serve all functions, some of which are medical.

A) Medical (Functional) Requirements

Generally, requirements describe functions and functional interrelations. Increasingly detailed functional requirements lead to hardware specifications. Medical functional requirements (e.g. X-ray imaging, surgery capabilities, storage requirements to cover a range of illnesses, patient restraints capabilities, etc.) together with mission requirements (aim of the mission, overall mission risk including the medical one) consequently lead to the definition of medical hardware.

B) Cost/Volume Relation

For any mission, a certain volume and mass, e.g. on board of the Martian transfer vehicle or the Martian surface habitat, represents a certain amount of money which derives from the overall mission expenses. This value (money/volume or mass) can change significantly for different missions. It is important to consider that this value also defines the range of financial efforts justifiable to develop new hardware with the highest performance and functionality for a certain volume or for a certain function with the smallest volume. This means one and the same function will lead to different hardware for different missions.

However, the cost/volume factor for a certain mission is difficult to define. The same is true for the assessment of developing costs for any medical hardware which would relate the expenses to its volume. Therefore the requirements in this work are directly formulated into hardware requirements. In addition, some medical hardware will not change under different mission scenarios.

C) Countermeasure Requirements

A similar approach as the one for the medical requirements has been done for the countermeasure requirements, meaning defining hardware to fulfil the countermeasure functions. In reference to the Mars mission project of the ISU'91 Summer Session Design Project, artificial gravity (0.38 g) was assumed for the transfer to Mars. However, according to Chapter 8.2.2 this does not relieve astronauts from performing countermeasure activities which have to be performed for at least two hours a day.

D) Private Space for Psychological Monitoring and Treatment

As mentioned before and described in detail in Chapter 1.4 beside the physiological challenges, the psychological implication will be most severe. For the architecture and design, the major design driver for psychological monitoring, diagnosis and treatment is a unit which features privacy and, if possible, a low noise level.

E) Recreation and Private Communication Area

Not just for psychological treatment, also for recreation and private communication, a physical unit is required, which should feature noise

shielding and privacy - this means similar requirements as for psychological treatment.

F) Virtual Reality (VR) Area to Combine VR with Physical Activities

With regard to a recent technology level of VR, it can be expected that VR will become a major tool in spaceflight for a range of purposes. Although there is normally no big space requirement involved with VR, in case it is combined with physical exercise, this would be the case.

8.4.1.2 Function Priority VS. Average Usage Time

The major design inputs mentioned in the section above have different weights in terms of priority of their usage. For example, any medical emergency treatment (function) has priority over, e.g. any kind of countermeasure function which can easily be shifted for a few hours or even dropped for one or two days.

On the other hand, countermeasure activities will be performed much longer compared to the total mission time than emergency treatment which might not happen at all during the whole mission duration. A good design should, of course, give easy access to everyday activities.

An assessment of the medical risks would determine the average amount of time required for a certain medical function. This would be an input into a trade-off process to determine which functions could use the same space and/or the same equipment and, therefore, could *not* be performed simultaneously. For example, if the bed is also used for psychological treatment (secondary use), in case a medical emergency occurs the bed has to be used for emergency hence the psychological treatment has to be postponed. This should not be a problem since medical emergencies rarely occur. However, when the crew number grows and the number of emergencies increases, combining these two purposes might not be the best solution anymore.

This example shows, that the mission scenario (in this example number of crew) has an impact on the internal physical design of the space facility of which (in most cases) the medical facility will be an integral part.

8.4.1.3 General Hardware Groups

Before going into any detailed design consideration concerning the best allocation of the different hardware units, a rough (pre-)grouping of the components into bigger units is possible, because many functions are entirely independent from others.

This process results in the following groups or units:

- Medical bed unit (some medical hardware integrated)

- Medical and Intensive Care (IC) monitoring and medical equipment unit
- Medical lab and further medical equipment (e.g. light system, computer monitors), eventually storage (mission dependent $\Rightarrow$ storage volume)
- Cabin environment monitoring unit
- Storage unit for medical supply and spare parts
- Countermeasure equipment (cycle ergometer, treadmill, LBNPD, etc.)
- Private space allocated for psychological countermeasure

A) Medical Bed Unit

The medical bed, used in case of partial or micro gravity rather than a human restraint system, might also contain a set of hardware. This hardware could include emergency ECG, infusion system and/or X-ray imaging, depending on the overall requirements for the bed, for instance if required as a transportation unit when going back to Earth.

B) Monitoring and Medical Equipment Unit

This unit shall include all of the equipment, which needs a direct link to the patient (except for the equipment incorporated into the bed). As this unit will be placed as close as possible to the patient, all line shall be designed to be short, reducing the problem of getting entangled in floating cables and hoses.

C) Medical Lab and Further Medical Equipment

This unit includes the remaining medical equipment which does not need to have direct connection with the patient, such as the medical laboratory, the refrigerator, centrifuge, emergency kit (entirely designated for emergency use!), etc., plus further medical equipment such as lightning, computers, monitors, etc. This unit does not necessarily incorporate itself in one single rack, for instance, the lights and arms could be attached to the ceiling or another rack as well.

D) Cabin Environment Monitoring Unit

For monitoring the regenerative water and air system, a set of hardware is necessary. Those devices can be fully automated and are grouped together. Hence, they don't require to be installed in a special location and do not require to be close to the medical laboratory.

E) Storage Unit

The storage volume depends on the mission. It might be one or two racks, or just a quarter or a half rack. Storage includes any kind of medical supply as well as spare parts and/or spare equipment if redundancy considerations require these.

F) Countermeasure Equipment

The countermeasure equipment depends on the number of crew members and the number of hours everyone has to perform countermeasure activities. The countermeasure system will be composed of four different devices, a treadmill, a cycle ergometer, a resistive exercise device, and Lower Body Negative Pressure Device (LBNPD). Depending on the mission (micro, partial, or fully artificial gravity, number of crew to be prepared for a gravity adaptation, etc.), the countermeasure equipment will be composed accordingly. Only for periods of about one month some medical equipment will be needed to monitor how the physical performance changes in the run of a mission. For this purpose, the necessary equipment can be moved temporarily.

G) Psychological Countermeasure

Psychological countermeasure will get a difference of attentions depending on the mission, especially its duration. Major issues in connection with psychological treatment are privacy and a low noise level.

8.4.2 Specific Design Considerations and Conclusions

The same order of discussion as in the previous chapter (Chapter 8.4.1) will be followed.

A) Risk

For a crew of six people, a 1+1 treatment requirement is derived. This means that two persons can be treated simultaneously by two medical persons. One person gets full medical support (bed, respiration system, etc.), while a set of the most important medical components will be available for the other person. This means, in the worst case, the DOCC must be large enough to accommodate four people. Therefore this trade-off between medical and mission risk becomes a *major design driver for the internal volume*.

B) Psychological Aspect

The requirement for privacy and low noise becomes another major design driver for space, because full privacy and good noise isolation can only be met by arranging a *separate private room*.

C) Stylistic Flexibility and Freedom

Although the number of racks is discussed elsewhere in this chapter, in many cases this is used merely as a counting unit for volume. In general, the internal physical design of the whole space facility will *not* be based entirely on modular racks anymore, but will make use of stylistic freedom to comfort human beings, which is a part of the psychological countermeasure approach.

8.4.2.1 Puzzling the Hardware into Larger Units

The following paragraphs will give a survey of the medical components that can be arranged together. The lists of components for the different units can be found in appendix H.

A) Medical Bed Unit

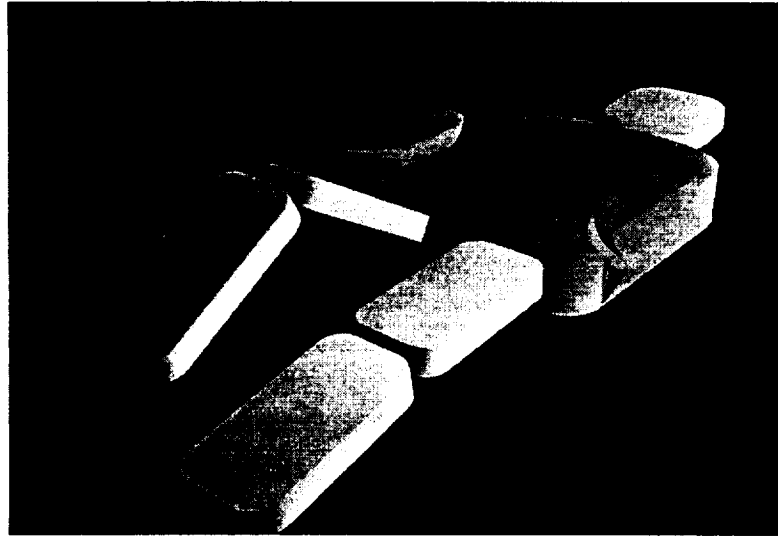


Figure 8.6 Draft of the Medical Bed

The medical bed consists of a main body, support structures for the head, and legs and arms. The whole system allows to get a patient into different positions as, for instance, dental chair, and should be very comfortable to sit for psychological countermeasure, recreation, or communication to Earth.

When retracted, the support structures for the head and the legs will be folded into the bed's body structure to account for small storage volume and small size of the door in the floor where it is stored.

Furthermore the bed can be turned (yawed) around about the height of the patient's shoulders allowing a medical specialist a good access to the patient as well as all sides.

For transportation, the bed can be detached from its main support. In addition, mounts shall be designed to connect a respiration system and a defibrillator with the bed easily.

A digital X-ray imaging device will be either attached to the bed or built into the bed, which would allow to take pictures and to give a view of them immediately on the monitors. The radiation source will be mounted on an arm on the ceiling.

Further medical equipment such as a small ECG, a pulse and blood pressure device, a intravenous pump, a temperature probe, an oximeter, a radiation

dosimeter, and a urine collection system will be incorporated into the bed in a way that the wires and hoses to a patient are as short as possible.

Two gloveboxes, one for surgery and one for dental operations, will be stored in the area under the bed when it is retracted.

B) Monitoring and Medical Equipment Unit

The medical monitoring, respiration, and most of the medical diagnosis and treatment equipment will fit into a box of approximately 80 x 60 x 70 cm (width x length x height) located next to the bed under the head of the patient (see appendix H for a detailed hardware list). This box will be deployable just like the bed. Some of the medical equipment such as the defibrillator or the ventilator will be detachable to be mounted to the bed, or carried to the place of an accident.

C) Medical Lab and Further Medical Equipment

This unit will be a standard rack of International Space Station which size is about 90 x 180 x 80 cm (width x height x depth) and contain all equipment to perform the work for medical analysis as well as life support examinations, for instance, of water and air. The rack will have a working place with a laminar airflow to fulfil microbiological safety requirements. It will further have the main computers and the emergency kit as well as a second portable breathing apparatus.

D) Cabin Environment Monitoring Unit

All automated units monitoring to cabin environment, some of which are quite voluminous, will be installed in the cabin environment monitoring unit. All equipment which can be found in appendix H will be summed up to about half the volume of a rack.

E) Storage Unit

It is estimated that for the approximate duration of three years of the Mars mission, two full ISS standard racks (90 x 180 x 80 cm) will be required to store pharmaceutical and medical supplies, blood supply, intravenous fluids, and spare parts and equipment for redundancy. A part of the racks will contain a refrigerator.

There will be a ranking of the stored items according to their required accessibility. This means that some items will be stored in places hard to reach, but insuring that every small volume is used more efficiently.

F) Countermeasure Unit

For a crew of six people for the Mars mission, the countermeasure equipment will consist of :

- 1 Treadmill
- 1 Cycle ergometer
- 1 Resistive exercise device
- 1 Inflatable Lower Body Negative Pressure Device (LBNPD)

The LBNPD will be used primarily for diagnostic purposes than for countermeasure, because there is no need for adaptation before descending on Mars because during the transfer the same gravity will be simulated in the transfer vehicle.

Having three countermeasure devices (treadmill, cycle, resistive exercise) for six people will allow enough flexibility to schedule the daily training slots per crew member. For redundancy a set of spare parts will be stowed in the unit as well.

These three devices will be attached to the module structure by a vibration isolation system, thereby reducing the impact on microgravity experiments and on the dynamic loading of the spacecraft structure.

8.4.2.2 Spatial Concept

A major idea of a spatial concept for a Mars mission can be seen in Figure 8.7.

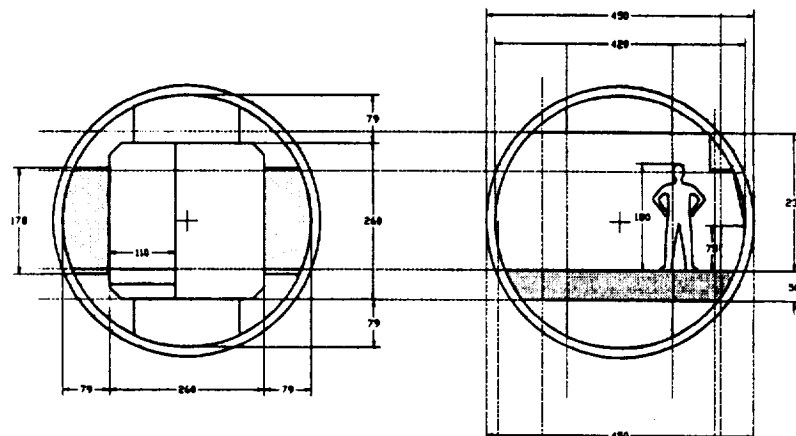


Figure 8.7 A Cross-sectional View of a DOCC

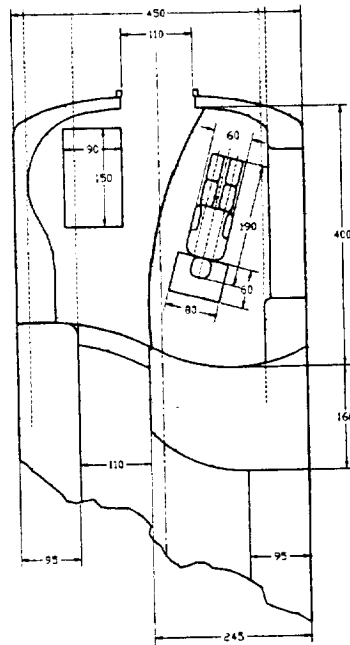


Figure 8.8 DOCC from Above

Figures 8.7 and 8.8 give a rough idea of the room concept. The major characteristics are:

- Floor raised by 50 cm
- Usage of nearly the full diameter of the station
- Curved stylistic element in the ground section
- Retractable translucent wall with high noise isolation capabilities

More detailed characteristics follow:

A) Elevated Floor

The reasons to raise the floor include:

- Create different impressions to the room
- Make storage space into the floor
- In case an airlock is in place, it would be easier to use as a hyperbolic pressure device
- Dust and bacteria have a tendency to float down and so to the lower room
- Suction system for sterilisation of the room could be more easily built into the floor (array of tiny holes)

B) Full Width of the Vessel

The (nearly) full width of the vessel will give a feeling of spaciousness - very important in a facility which is rather comparable to a "sardine can".

Moreover, the requirement to treat 1+1 injured persons, meaning that another 1+1 person have to be in the same room performing the medical treatment, result in the demand for space for 4 people.

The "big" room can also be well used as a virtual reality (VR) area enabling a "higher degree of (physical) freedom" e.g. for a combination of VR and physical exercises or games.

C) Curved Walls

The curved walls shall indicate the design attempt to comfort humans stylistic sense better than flat walls normally do. The general aim is to create a kind of "living room atmosphere" to stimulate positive associations with medical treatment, countermeasure activities and/or psychological treatment.

D) Retractable Translucent Wall

A retractable translucent wall with high noise isolation capabilities shall enable to separate the big room into two smaller rooms to perform different tasks independently, and therefore much more space efficient. Ideas for its usage are outlined in more details in the following section.

8.4.2.3 Further Ideas

A) Arm System

A system of four arms mounted on the ceiling will give assistance during medical operations. The arms will allow flexible configuration. There might be a fresnel light system, a monitor system (probably permanent) and small tables to carry surgical instruments, or the X-ray source.

B) Fresnel Light System

In analogy to a viewgraph projector, a light could be arbitrarily focused by a film-like fresnel light-weight lens and require very little volume. Variable focusing could be then realised rather easily.

8.4.2.4 Usage Concept

The four major configuration possibilities of the medical facility are shown below in Figure 8.9:



Figure 8.9 Different Usage Configurations

(A) In this situation, the bed and the medical equipment box are deployed and the translucent wall is closed. This might be the case when a person is medically monitored, for example, recovering from a medical operation or accident, being sick, or performing a psychological test. At the same time countermeasure activities can be performed in the other room as well as combined with VR activities.

(B) The wall is retracted, and the medical bed is turned into the room. This gives best access to a patient from all sides as well as to the medical equipment box. Furthermore, the medical facility is closed to the rest of the other facility. In this situation, simple medical operations can be performed as well as complicated surgery.

(C) Situation C indicates non-medical use of the medical bed and the DOCC facilities. This can be psychological countermeasure, private communication to Earth, VR activity, or just recreation in a silent room.

(D) When the bed, the medical box and the wall are retracted, the full room can be used, for example, for countermeasure activities, group VR games, or VR mission training.

8.4.2.5 Some Three-Dimensional Sketches

The following figures 8.10 to 8.15 shall give a better idea of the space and the usage concept of this design draft.

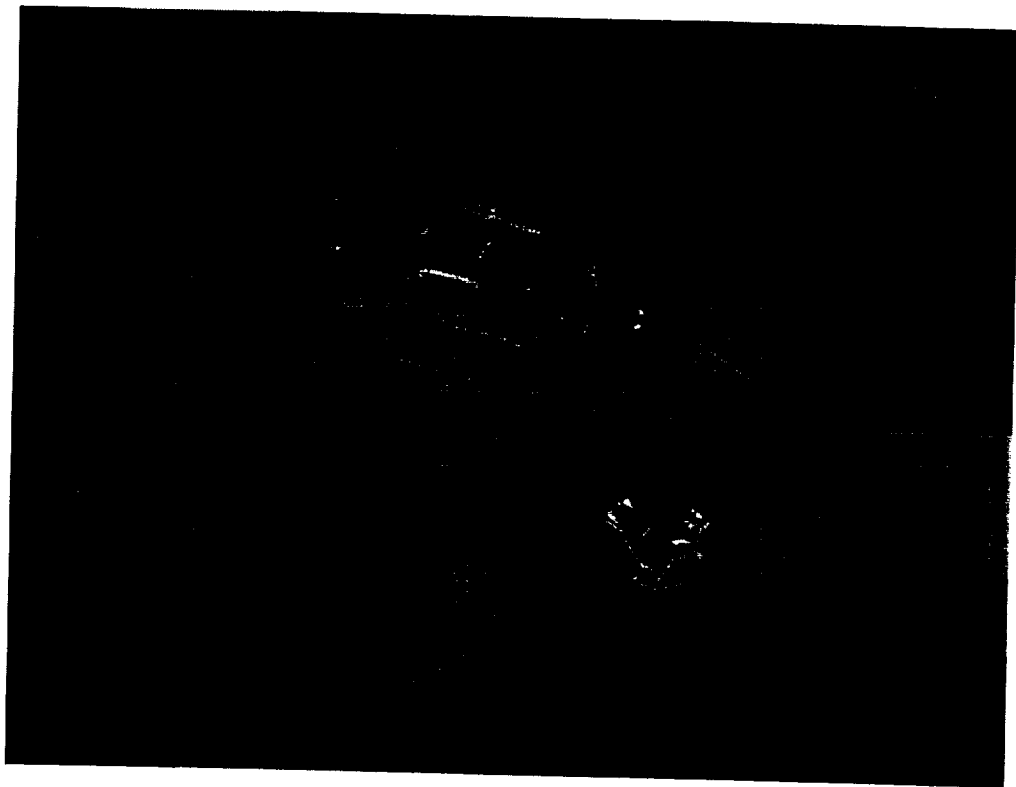


Figure 8.10 Medical Facility Separated by the Retractable Wall



Figure 8.11 Usage Scenario A According to Figure 8.9



Figure 8.12 Usage Scenario B According to Figure 8.9



Figure 8.13 View of Usage Scenario B



Figure 8.14 View of Usage Scenario B



Figure 8.15 View of Usage Scenario B

8.4.3 Virtual Reality Facility

The Virtual Reality Facility of the Martian DOCC is one of the most extensive possible VRF designs and serves the full array of possible applications mentioned in the core DOCC VRF design (Chapter 4.3.3). It plays an especially important role in this Martian scenario because it can mitigate many of the human factors problems inherent in long-duration space flight and planetary exploration. This VRF will likely carry VRF body suits and goggles for each crew member on board, because certain practice training scenarios will require simultaneous physical co-ordination among the entire crew in a virtual reality environment.

A) Medical Applications

The Martian DOCC VRF will serve the medical facility in the areas of medical training, surgical practice, psychological therapy, and psychological testing. Specific information about these medical support applications of virtual reality in the Martian transfer vehicle and base scenario are covered in Chapter 8.2.8.

B) Mission Training

During the Mars transfer flight the VRF will assist the crew in continuing to practice landing procedures and base construction. The long duration of the transfer flight makes it crucial that the crew be able to continue to learn and practice the skills they will need on the surface while they are in flight. An identical VRF on Earth will enable ground personnel to assist the crew in training and development of solutions to problems that arise. Once on the Martian surface, the VRF will primarily serve as a simulation environment in which procedures developed on Earth may be practised by Marsnauts in an identical simulation environment to that in which they were developed on

Earth, prior to executing them in reality. This will speed supplementary training and minimise the potential for miscommunications between Earth-based mission teams and the Marsnauts.

C) Entertainment

The ability to be entertained is crucial to the psychological health of the crew, especially during the transfer phase of the mission. The VRF can provide entertainment in the form of actual exercise and simulated games, as well as simulated environments and movie-like programming. This technology is a potentially lucrative spin-off in the future.

D) Exercise

In the reduced-gravity environment of the transfer vehicle and on Mars, the VRF will supplement exercise countermeasure equipment which is standard aboard long-duration space habitats such as the Mir Station and the International Space Station. It will enable the Marsnauts to exercise in a virtual environment and in the context of varied and enjoyable recreational activities, even as they use the same standard muscle exercise equipment found on all space vehicles today. For example, Marsnauts will be able to run through a simulated outdoor terrestrial environment of their choosing, or run through a simulated obstacle course as part of an arcade-style game. Alternatively, they might exercise by testing their rowing ability against the best college crews in the world at the Henley Regatta on the Thames River. Of course, other forms of exercise could be devised for such long mission (Figure 8.16).



Figure 8.16 Another Possible Form of Exercise for Bored Crews on Long Missions

Experience with Cosmonauts on Mir has shown that some Cosmonauts find it difficult to fulfil the prescribed exercise countermeasure program on flight of comparable duration to the Mars transfer flight due to the rigorous, long and repetitive nature of the required countermeasures. Although both the transfer vehicle and the Martian base will be reduced gravity environments rather than microgravity environments, the ability to exercise is still important. First, we have no data on the effects of reduced gravity for such long-duration on the human body. Furthermore, we will not be able to gather such data prior to the Mars mission. Second, the ability to exercise is important to psychological health of the Marsnauts. Finally, exercise will be an important part of any physical rehabilitation program which may be necessary after an injury.

E) Private Video Communications/Private Space for Crewmembers

The VRF will give Marsnauts the ability to communicate privately with family and friends on Earth, which represents a significant advantage over traditional two-dimensional video both in terms of privacy and simulation of reality. A corollary benefit of the VRF is the ability to use the virtual environment as a private personal space. A customisable virtual environment could be created by each crew member, and available to him or her at certain hours of the day. This represents a significant cost and space savings over other long-duration mission designs in which it has been deemed a necessity to provide a private physical space for each crew member.

8.5 ADAPTATION TO CORE DESIGN

8.5.1 Communications Constraints On A Mars Mission

This is a brief discussion of the telecommunication characteristics/constraints assumed on a hypothetical mission to Mars where the DOCC module could be integrated. The basic requirement for the DOCC's full operability is to have a continuous digital communication link with Earth, able to support applications ranging from low rate data transmission to high rate high quality video-images.

We assume that the communication network Mars-Earth will be established in several steps, prior to human missions. The ideal system would consist on three communication satellites placed on Mars stationary orbit plus two communication relay satellites in the Earth-Sun Trojan points. All these communication satellites should be deployed and fully tested before the first human missions. The band of operation of these satellites will be Ka-band to allow the high data rates and high directivity required in the communications hardware.

On Earth, the three NASA Deep Space Network (DSN) stations will be used as main communication nodes. They are needed to provide continuous communications between Mars and Earth. Their capability will be upgraded to operate in the proposed higher frequency band. These ground segment will be

complemented by additional receiving stations specially designed for the Ka-band.

The data received by the DSN on Earth will be relayed to the Ground Control Centre to be distributed to various destinations. The particular data corresponding to DOCC activities will be distributed to the Outside Medical Support.

Due to the vast interplanetary distance (one way communication Mars-Earth need between four and twenty minutes depending on the specific orbital position) retransmission of data is not practical. Instead, forward error correction coding will be used to ensure data integrity.

In order to reduce the amount of data transmitted, up-to-date compression techniques (both lossy and lossless depending on the application) will be used.

This communication network shall be designed with flexibility, reliability and quality in mind:

- The Mars-Earth link uses multiple frequencies to achieve redundancy.
- The three communication satellites in the Mars-stationary orbit overcome the problem of occultation due to the rotation of Mars as well as provide an excellent coverage of the Mars surface.
- The Trojan relay satellites overcome the problem of communication black-outs when the Earth-Sun-Mars conjunction occurs (communications can be disrupted for nearly two months). Although a single Trojan relay satellite would be enough, the second one provides a redundant link.
- Additional ground segment Ka-band stations to provide spatial diversity to overcome the problem of strong rain attenuation.
- Forward error correction coding and compression techniques optimise the performance of the link.

The current developments on Ka-band technology indicate that it will be ready in a few years to be applied for deep space communications. Optical inter-satellite links are seen as the technology of the future, offering even greater information carrying capacity and compact communication payload size. However there are still a number of improvements to be carried out (improvement of the receiver sensitivity, increment on the pointing accuracy of the optical instruments,...) which seems to indicate that it will not be available for the first manned missions to Mars.

Of course, the particular conditions of this Mars scenario, mainly the time delay affect the capabilities of the DOCC module.

As mentioned previously, this time delay between Mars and Earth makes impossible to have real-time video-conferences, tele-surgery or any other real-

time application that could be carried out in an orbital station around Earth (or even in the moon if a small delay can be allowed).

Other important considerations are that the DOCC informatic system should minimise the dependencies from the Earth. A particular example would be to avoid receiving software, databases or anything which can be received by the transmission link in hardware media. Whilst for other scenarios near Earth (remote Earth locations, Orbital Station, Moon) it could be possible to distribute regularly CD-ROMs with information updates, the distance Mars-Earth converts this in a bad solution.

Finally, it should be considered that at the time of a manned Mars mission the compression techniques and protocols will certainly be slightly different. As said TCP/IP will probably have evolved towards higher performances. Some emerging ISO drafts such as e.g. MPEG-4 (very low bitrate audio-visual data) or MHEG (Multimedia Hypermedia Experts Group) might then be commonly used (see URLs in the References). It is impossible to determine if today's data formats (JPEG, TIF, etc.) will still be used in say fifty years from now.

8.5.2 Mars Modifications to Core Operations

8.5.2.1 User Selection and Training

Users will be selected according to the criteria for long-duration missions; hence, they will be selected according to the two-tier scheme, using the "select-in" medical criteria as detailed in Chapter 6.1.1. Thus, the crew will be selected as a team. The crew will be put together such that two members of the crew qualify to be trained at a Specialist-level, and the other members of the crew, at the Medic-level.

8.5.2.2 DOCC Facility Start-Up

A) Initial Supply

On a long-duration Mars mission, the initial supply of a remote medical facility must consider the entire mission life. Since the facility cannot easily be resupplied, the facility will require sufficient stock to sustain it throughout the mission life. An option to an extensive initial supply, particularly for a Mars base, might be to send a pre-launched supply ship. This pre-launched ship would be launched in advance of the actual mission and could either remain in Martian orbit or make an actual planetary landing. The mission team would then rendezvous with the supply ship, thus reducing the need for a full initial stock of medical supplies. This pre-launched supply ship could be co-ordinated to provide supplies other than medical, such as, propellant, food, energy production and/or agricultural equipment, etc.

B) Test Verification

Since the remote medical facility cannot be easily supplied with spare parts, the design of the facility may not utilise the line-replaceable unit concept.

With a more system-level design, the initial testing of the facility as an entire complex would be much more critical. It is expected that testing required prior to launch, utilising the interrelation of all system components, would be more extensive. As no replacement of sub-system level components would be possible, the initial reliability of the system design would need to be critically analysed.

8.5.2.3 Procedures and Protocols

Since the duration of the mission is so long, effective in-flight training is vital, and must be based around pre-defined procedures. The in-flight training should be as realistic as possible and probably as enjoyable as possible, which indicates the need for interactive computer based training and Virtual Reality technology.

The increased distance will mean that more crew autonomy is required. This will drive the development of improved human-procedure interfaces, using technologies like notebook computers, personal digital assistants, wearable computers and voice control. The ground control centre could uplink validated procedure sequences which are then rehearsed interactively by the crew and then executed autonomously. As an example of a problem which combines the need for in flight training and crew autonomy could be rehearsing an unanticipated EVA manoeuvre to repair a damaged component of the Mars transfer vehicle, and then executing the task autonomously to cut down the time required outside the spacecraft. A virtual reality simulation could be developed at the GCC and then uplinked to the spacecraft to be practised.

The paper hardcopy backup for the expected core procedures and protocols must be maintained due to its high reliability and portability. Any electronic hardware used to augment the paper procedures will need to be radiation hardened and this may cause a considerable extra cost and a time lag between the technology developed for the commercial Earth markets and that which is qualified for spaceflight, especially a long duration Mars mission.

8.5.2.4 Maintenance and Logistics (see Chapter 6.2.2)

In the Mars Mission, especially in transportation phase, all spare items will store on board and no logistics required. After landing, in Mars base phase, few logistics is available in very long intervals (more than one year).

8.5.2.5 User Deconditioning

Due to the length of the mission, deconditioning time for the returning crew will be long-term. It will last at least three months, although exact length will vary for each individual. The deconditioning program will emphasise treatment for long-term exposure to partial gravity effects, for exposure to radiation, for the long-term effects of isolation, and for chronic stress.

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Section IV

Business and Legal Issues

Chapter 9

DOCC Business Aspects

This chapter will provide an introduction to the aspects of business and space commercialisation of the DOCC. The commercialisation aspect of the DOCC is paramount, for it appears from a politico-economical perspective that the success and viability of a given space project is directly measurable through both the tangible and intangible returns that it is likely to generate. These returns will include monetary and technological gains for investors, as well as general increases in the availability of quality health care for all humans in all areas of the world.

What exactly is the product DOCC? What are the market issues? Who will develop the product DOCC and how? How will the commercialisation occur? What are the costs? What growth opportunities exist? This chapter will attempt to answer these questions.

9.1 THE DOCC “PRODUCT”

9.1.1 The Product Definition

The DOCC “product” is a health care facility which combines specially developed hardware with support services provided through the ground control centre function. Thus, it can be seen either as a tangible hardware product, a service product, or a combined package of both elements. With the anticipation that the DOCC may be used by both medically and non-medically

trained specialists, it is recommended that the design of the DOCC emphasise user-friendliness.

Considering the heterogeneity of the geographical areas where the DOCC is likely to be used, it is envisaged that the ground segment will optimally respond to DOCC users' demands. This includes international links to medical facilities and practitioners outside of the DOCC Ground Control Centre, as discussed in Chapters 5 and 6. In order to accommodate the needs of customers around the world, it is envisioned that these medical links will provide language compatibility with the end user.

Although the primary mission of the DOCC is to maintain human health and performance, it is also likely that the DOCC will eventually be used for experimentation purposes. This could lead to further future innovations, both in advanced technologies and medical procedures. This additional "product" will entice companies, particularly in the medical industry, to invest and participate in the development of the DOCC.

9.1.2 "First-Generation" Facilities

In order to meet a growing market need, a variety of organisations have, in the past, developed methods of treating health care problems in remote areas. Examples of these include:

- Oil and petroleum companies, such as British Petroleum, who have a medical care department which has specific procedures and protocols for medical treatment on oil rigs and platforms. [Leadbetter, 1996]
- Antarctic support organisations, such as the Australian National Antarctic Research Expeditions, which runs four permanent Antarctic facilities, equipped and staffed to treat general population medical conditions in all climates of the Antarctic. [Sullivan, 1996]
- Government defence/military organisations, which have developed telemedicine and emergency care facilities for battlefield use. [Lathan, 1996]
- National space organisations, such as NASA, who has developed a system which addresses crew health care in on-orbit vehicles. This system is specifically designed for each flight, with features including designated crew medical officers and basic crew medical training. However, international medical ground support is not included in this system.

All of the "first-generation" facilities identified by this project were initiated in response to an "industry-specific" need, and all of them provide care on regional levels only. Because they are neither modular nor globally networked, it can be seen that the competitive advantages of the DOCC product are:

Strengths	Weaknesses
• Ability to support the treatment of most medical conditions regardless of external environment • High technology development can be applied to both the DOCC and other products • Rigorous testing in both the space and Earth environments will assure reliable and high quality health care • High degree of modularity will allow penetration of a wide variety of customer segments	• Imbalances between the hardware segment and the service segment could compromise quality of care • DOCC technologies developed for space uses may not always “cross-over” into Earth DOCC’s (particularly those adapted for high radiation and micro-gravity environments)
Opportunities	Threats
• Low competition in target markets • A growing population in areas with undeveloped health care infrastructures will provide a growing market for the DOCC on Earth • Adoption of DOCC hardware and technologies may create industry shifts that will allow greater market opportunities for DOCC service support	• Increasing space budgetary constraints may limit project development • Investors may not wish to wait for returns in what could be a long term project • International co-operation can complicate co-ordination and increase project costs, and does not always guarantee giving the contract to the best contractor

Table 9.1 SWOT Analysis

9.2 MARKET ISSUES

Defining clearly the market for a product is an essential step toward its success. This section is aimed in presenting the fundamental market issues to be considered concerning the DOCC.

Marketing can be thought of as the process of decision making and actions involved in defining a product’s design and characteristics, its pricing policy, its promotion strategy (i.e. advertising content and media selection) and its distribution policy (i.e. channels, means of transport, territory covered). These are the four commonly used marketing variables which constitute the “marketing mix”. Since in Section 9.1 a description of the DOCC product was

presented, this section will describe the remaining three variables as well as the potential customers of the DOCC.

9.2.1 Potential Customers

Who is the potential market for the DOCC product? This is the main question an investor or funding organisation will ask when deciding to invest in a determined project. This section defines who this potential customer is, considers the market evolution in three phases: an initial phase where the product is only for low orbit applications, a second phase where it could be deployed on a terrestrial basis and a third phase where it could be implemented for an interplanetary mission. Rather than defining in detail the characteristics of this market, this section's objective is to define a starting point from which to begin a market research study.

The following groups of customers were distinguished:

- Governments of already developed nations (i.e. space agencies) and of developing nations, as well
- Private sector
- International non-profit organisations concerned with human health care

Table 9.2 presents these groups of potential customers distributed in the three phases. The second column addresses the applications the DOCC could have for these market segments.

Phase	Applications	Customers
I	Orbital space mission	Governments of nations with well developed space programs
		Private sector through joint ventures
II	Earth value-added services (i.e. world-wide network providing services: telemedicine, law consultation, others)	Private sector (i.e. hospitals, undersea operations, oil platforms, remote agricultural facilities)
	Peaceful and humanitarian purposes	International non-profit organisations
	Earth telemedicine and teleeducation	Governments of nations with space programs in development
III	Interplanetary mission (i.e., Mars)	Governments of nations with consolidated space programs

Table 9.2 DOCC Potential Customers

The marketing phases in Table 9.2 are presented sequentially for simplicity; however, they will overlap in time, and parallel development of terrestrial and space applications for the DOCC will eventually take place.

9.2.1.1 Governments

Developed Nations

In the first phase, governments of developed countries will have an active participation in space related applications, specifically the use of the DOCC for orbital missions. Again, during the last phase, governments will be involved and give impulse to the use of the DOCC for interplanetary missions.

These countries might be interested in implementing Earth applications, as well. In a vast majority of the developed countries, the health care system is supported by the government. The citizen pays taxes and the government sustains the health system by investing in medical care.

In this case, health is an accessible good provided by the government. The public health systems of a country are a major potential customer of the DOCC. Even if the capital investor decides not to place his money in this business, the government has to guarantee the citizens appropriate and reliable health services.

Governments are interested in reducing the budget assigned to medical care. Gaining efficiency is a first step toward this eventual reduction of costs. One of the main failures of the actual health care systems is to concentrate in treatment of illness rather than in prevention. The DOCC could be a means to provide effective preventative methods and lead to a reduction of the number of patients hospitalised, and of the investment in medical care.

The DOCC, as a reliable, modular health care facility supported by a ground system, can satisfy this demand. The DOCC may be useful for submarines, underground mining, remote agricultural facilities, remote expeditions in isolated areas, or other activities planned by governments. “Hands-on” medical training facilities and space medicine education are other services that could be provided.

Governments are the leading entities when a country encounters a natural disaster. The use of DOCC technology to provide health care for people affected by an event of this type is an option that could be very attractive.

Developing Nations

The deployment of the DOCC in developing countries will be possible through the implementation of terrestrial applications; this will need a different commercialisation approach. A market study in these regions would be the recommended initial step in order to proceed with the development of this strategy.

This potential market will be more evident in Phase II when the product has already been used for space or terrestrial purposes in other nations. Part of the

acquired expertise could be transferred to countries with space programs in development through entities like the United Nations.

Training is a major concern and must be done adequately to ensure the satisfaction of the customer and an appropriate deployment of the product among different nations. In Section 6.1.2 from the DOCC Pre-Flight Operations section, a description of the training issues is presented. The provision of training for these nations could be done through the Ground Control Centre described in this section. The training could eventually be free of charge or as part of an agreement reached among countries.

Some of the main uses this market may have of the DOCC are:

- National and international telemedicine projects
- Teleeducation programs
- Emergency facilities during natural disaster events

9.2.1.2 Private Sector

The private sector has a role as a customer in the two initial phases depicted in Table 9.2. In the first phase, it is working together with the government through the creation of joint ventures.

In the second phase, where terrestrial applications are addressed, the DOCC will be directed toward a wide number of customers of the private sector. Among these potential customers are:

- hospitals and health care institutions
- companies involved in the medical business (i.e., pharmaceutical, equipment manufacturers)
- future companies refitting or developing spacecraft orbital facilities for commercial applications
- private space agencies with personnel who need special space medical training
- undersea operations (i.e. sea-mining)
- sea-farms, oil-platforms and co-operative agricultural units
- medical educational institutions interested in a down-sizing

Some other potential Earth application customers for the DOCC are companies in the business of commercial cruise ships, transatlantic airplanes carrying “higher health risk” passengers and organisers of large events where on-site medical care has to be available (i.e. concerts, sports, political, and medical events).

Even though it seems the private sector's major role takes place in Phase II, this potential market should be considered from Phase I and approached by the DOCC's sales force since then. During Phase I, these potential customers should be constantly informed of the evolution of the product within the market. They must be targeted directly through an aggressive promotion strategy.

9.2.1.3 International Non-Profit Organisations

International organisations have a peaceful goal, and they seek to provide improvement in the quality of life for mankind. Organisations like the Red Cross, World Health Organisation and *Medecins sans Frontieres*, among others, pursue a good health standard for mankind.

These organisations represent a market with clear humanitarian objectives and are willing to invest in order to meet them successfully. On the other hand, cost-benefit studies should be done in order to convince this market to invest in the DOCC. During Phase II, this segment has to be taken into account and addressed strongly by the sales force. Everything that applies for the private sector segment applies for this segment, as well.

9.2.2 Customer Buying Decision

In a customer's buying decision, there are five different roles that entities (i.e. persons, companies) can play: initiator, influencer, decider, buyer and user. Some of these elements have been addressed in one way or another in the previous sections.

This section is aimed in mentioning the major role that insurance companies may have as an influencer in the customer's buying decision. Insurance companies could be a stimulating element to boost the number of products sold. To illustrate this fact it is worth making reference to the boost given by the car insurance companies to the market for anti-theft devices, and by the fire insurance companies to the market for items such as fire extinguishers and smoke detectors. [De Dalmau, 1996]

9.2.3 Price

Two sets of factors play a major role in defining the price for a given product: those generated internally by costs and those emanating externally from the market.

The production of the DOCC must be aimed in reaching the lowest levels of cost without sacrificing the overall quality and reliability of the final product.

If a product is developed for a non-profit perspective, the price is not a major issue. On the other hand, from a private sector point of view, a certain level of profitability is always expected. This percentage of revenue and return on investment will have a direct impact on the price.

One of the major factors that affect the price of a given product is the existence of a competitive market. It is not expected that the production of the DOCC will take place in a competitive environment. For this reason, the price will be basically determined by the cost.

The pricing strategy should be developed based on the above assumptions and on the following terms:

- If a customer acquires the hardware and software elements that compose the DOCC, the price will be defined from a product perspective (i.e. one-time acquisition and maintenance service).
- If the customer subscribes to DOCC services, he should be charged on a timely (i.e. monthly, yearly) and/or on a transaction basis (i.e. amount of information processed).

9.2.4 Promotion

The DOCC is a specialised product that needs a specific promotional strategy. In order to let the potential market learn about the DOCC's characteristics and benefits, it is recommended to develop a strategy based in the following general terms:

- Direct marketing approach through the personalised visit of specialised personnel to the potential customers.
- Participation in international space and/or medicine related congresses, symposiums and exhibitions. This participation should be through presentations and booth display of the product.
- Demonstrations in universities and academic institutions specialised in medical education.
- Development of educational documentaries on television and joint participation with subscription channels (i.e. CNN, Discovery Channel).
- Written material to be handed directly to the potential customers of the DOCC. This material should be focused on the benefits of the product and it provides support to the personal visits and to the exhibitions.

9.2.5 Distribution Channels

To define the distribution channels for the DOCC product it is necessary to separate its two main application environments: space and Earth. From the space environment point of view, the main distribution channel will be the DOCC manufacturer. The DOCC direct sales force will also play a major role in reaching specialised potential customers.

In the Earth operational environment, it is important to recall that DOCC hardware facilities as well as single subscription services could be available. The main distribution channels for these cases are:

- DOCC hardware and software: the channels are the manufacturer and the direct sales force.
- DOCC services: the channel would be the entity responsible for providing the service to the end user (i.e. hospitals connected through a network using DOCC technology and providing health services to remote end users).

9.3 COMMERCIALISATION

Space commercialisation is the establishment of procedures, incentives and business ventures in order to exploit the attributes of space for producing and marketing products and services. [Cohendet, 1996]

Governments' support is initially needed to start and advance a project when users and providers do not have the resources to develop new technology on their own. But the commercialisation, i.e. the standardisation of a product on a large scale, is the action of the private sector and not of the government.

The DOCC product may create new demand supporting infrastructure systems and support. For example, one of the application scenarios of the DOCC could be an Orbital Hotel. This scenario also indirectly targets the LEO communication business. The LEO communication business market and technologies are well understood, and the industry, which is new, may considerably increase.

9.3.1 Development

The commercialisation of the DOCC project can be divided into two main stages: the development stage and the operational stage. As Table 9.3 shows, government plays an active role in the first stage to advance the project. This is explained by the fact that the private investors will take zero risks whenever possible, and will look for a rapid return on their investments.

Thus, the private sector appears only in the second phase, in a hybrid structure with the public sector. This step is important in the development of the project, as the project raises the interest level of the private sector. The implementation of the project as a new service or good in the marketplace depends on the lead taken by the private sector.

The private sector will be the main actors in the third phase when the DOCC is a reproducible and commercial "product/service" on Earth. In this last phase the government can be considered a customer like the private sector customers, and no longer a main actor, since he has now relegated his role to the private sector.

	Development Stage		Operational Stage
	<i>Pre-development Phase</i>	<i>Phase I</i>	<i>Phase II</i>
Characteristic	Research / Development of the Project	Development of the project by Industry for new commercial markets and commercial infrastructure	1. Applications to market place on Earth 2. Production in more large scale
Main actors	Governments (or IGA)	1. Governments 2. Industry	Private sector
Role and actions	1. Boost the Project 2. Grants or subvention to Industry driven research	Expand the infrastructure and the commercial development	Commercialisation of the service on Earth.

Table 9.3 Phases of Development of the DOCC Project

Sections 10.7.2. and 10.7.3 also provide a description of how the private sector will gradually be involved in the development and production of the DOCC.

9.3.2 Barriers to Commercialisation

As in all commercial of space ventures, there are some barriers to take into account in the commercialisation of the DOCC project. The main barriers are:

- High perceived risk by the private sector. The risk will be essentially a market risk for the DOCC.
- Lack of interaction between potential users and sellers.

The main solutions to prevent these risks are mostly to be done by the Government during the first phase. The actions to be taken are :

- Developments of infrastructures for the implementation of DOCC
- Dissemination of information, and demonstration of programs
- Transfer of technology programs from space to the Earth (see Section 9.3.3)
- Financial incentives
- Institutional arrangements

The commercialisation of the project will be successful with the transfer from one DOCC working in outer space, to several DOCC's available on Earth. Thus, a real market will appear for the DOCC, with customers, suppliers, and

other markets linked, like equipment, insurance, or medical and pharmaceutical industries.

The terrestrial applications of DOCC will have different aspects as the different customers may not have the same needs.

9.3.3 Transfer of Technologies

There are three kinds of technology transfers which are applicable to the DOCC :

1. *Within the Industry*: For example, the contractor that built the DOCC may be looking for a certain technology derived from the DOCC-developed technologies. This company will need to develop a relationship with its subcontractor regarding their DOCC-developed technology. The subcontractor will retain the intellectual property rights, but will come to an agreement with the contractor regarding the application of the technology.
2. *Commercialisation of DOCC*: The goal of the actors is to transfer the technologies that have been developed from space to the Earth.
3. *Spin-off*: While developing DOCC technology, the contractor may develop other technologies which were not expected.

These potential technology transfers depend on the contracting policy, and should refer to them when issues appear. The space organisation will endeavour to favour these new technologies.

The DOCC being a space orientated project, the R & D will be of a very high standard. Parallel to marketing the DOCC package, the commercialisation of the various technologies developed will be equally paramount.

An example can be given with the case of ambulances. The major constraint that ambulances have to confront is the number of facilities to be selected within the limited space available. The smaller the utilities, the more that can be integrated in the ambulance, thus increasing its operational potential. This is just one example where the highly technical products could be promoted into existing markets.

Consideration should also be given to the changes in the existing operational procedures of such markets, as they may need to adapt with the development of new technologies. In the example of the ambulance, if more complex medical procedures may be performed within the ambulance because of adoption of DOCC developed technologies, it may also be assumed that more complex training may be required for drivers/attendants of the ambulance. This could provide both additional barriers to entry for the DOCC product and market opportunities for additional provision of products and services.

As illustrated above, the commercialisation is not merely consisting of the distribution of DOCC on remote sites, but will equally seek to promote the advanced technologies and services as a replacement for current utilities in existing markets.

9.4 COSTING

9.4.1 Cost Breakdown

All agencies or private institutions are more and more concerned by the cost of any project because money has become the key factor. The decision-making processes, which define the existence of a project and influence the way it is conducted and financed, all involve cost related issues. The aim of this section is to show a cost estimate of the DOCC project at today's conditions and also to detail the costing methods that have been used to reach these estimates. All cost estimates have first been made for a Low Earth Orbit application as a reference and then extrapolated to earth application on the one hand and long duration space application (i.e. Mars mission) on the other hand.

In order to reach a realistic value and have a relevant overview on the cost drivers, the costs must be separated within different categories:

- *The development costs or non-recurring costs:* These costs relate to the design, validation and testing processes that are necessary before the manufacture of the first unit.
- *The recurring costs:* These costs exist in the price of the various units that are manufactured starting with the first model. The recurring costs are subject to economies of scale, the significant decrease from one unit to another because of the learning effects of production.
- *The transportation costs:* The transportation costs represent a significant part of a space project because of the sophisticated technologies and significant operational efforts involved.
- *The maintenance and operational costs:* These costs add all the yearly expenses that are necessary to run the project on a nominal basis. They need to be taken into consideration when assessing the price and evaluating the return on investment.
- *The insurance costs:* All the parties involved in the DOCC such as financing entities, developing contractors, the launching party or operation participants will have to consider risks during the pre-launch, launch, use and post useful life. The risk exposure for each party exists in one or more of the above phases and for different types of risks such as direct loss or physical damage, indirect losses, contractual obligations and public liabilities. Most of those risks can be covered by specific insurance through specialised companies. The decision to cover the various risks will not only be taken for DOCC purposes but will consider the risk coverage policy for the overall mission.

In addition, it appears that the cost of insurance is complicated to evaluate because it combines space insurance with medical coverage in an uncertain legal framework.

9.4.2 Cost Estimation Methods

For each of the above categories, different techniques can be used for cost estimation: cost by analogy, parametric cost analysis or engineering cost analysis. In the specific case of the DOCC, we have used alternatively or simultaneously the three methods by applying the following method.

9.4.2.1 Non-Recurring and Recurring Costs

The non-recurring and recurring data that are available concern mainly the cost of equipment available for terrestrial applications, equipment used on Mir station or equipment which will be used in the International Space Station. In order to come to a realistic cost, the rationale used to estimate the cost is a three steps approach:

1. *Terrestrial Analogy*: For each item (hardware or software) an estimation is made on the level of modifications which will be necessary to implement and upgrade the existing terrestrial item into a space item. For example, a mechanical device may require engineering for reducing mass and volume and an electronic equipment will have to be modified to sustain different environmental conditions (i.e. radiation). All space items will require a significant reliability improvement campaign as well as extensive testing. This is represented in Figure 9.1.

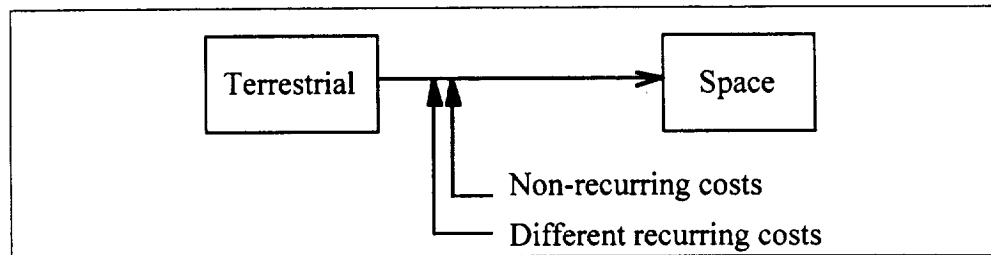


Figure 9.1 Estimate by Terrestrial Analogy

2. *Space Analogy*: In the case where the above mentioned item already exists for space application, a validation is made of the previous estimation taking into account a technology improvement factor and a learning effects factor. This is represented in Figure 9.2.

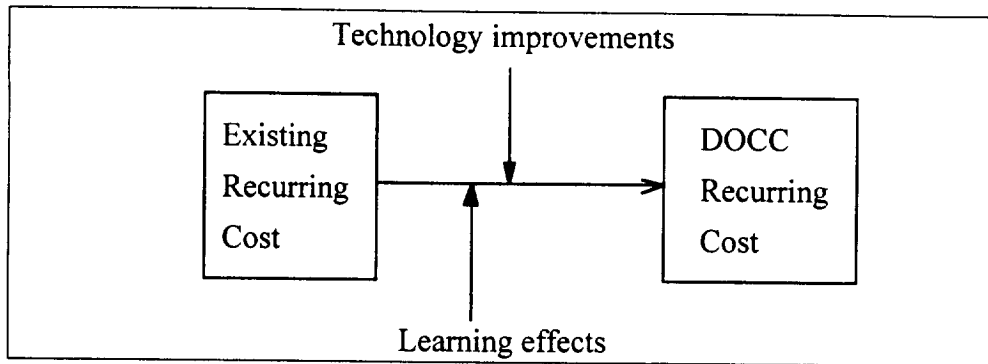


Figure 9.2 Estimate by Space Analogy

3. *Parametric Estimate*: On a case by case basis, the estimates can also be validated by means of a parametric calculation. It appears that most accurate models for electronic equipment are based on a price per kilogram formula model such as Figure 9.3:

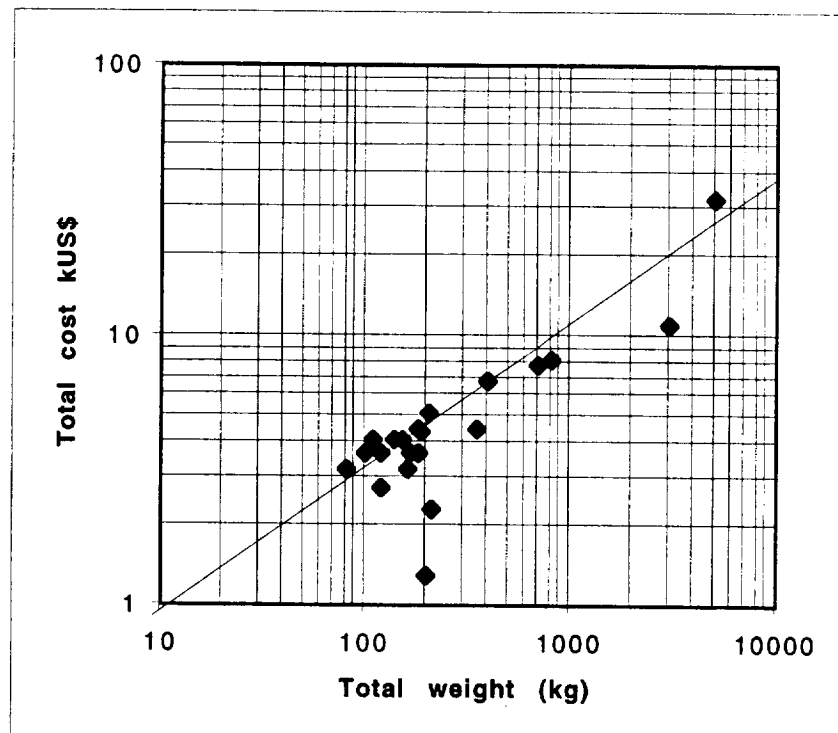


Figure 9.3 Parametric Estimate

9.4.2.2 Transportation Costs

The transportation costs are estimated on the basis of data on future space transportation systems using cost per kilogram models which are available for different types of missions (orbit, duration, etc.):

Cost per kg to low Earth orbit :	4.8 kUS\$ / kg.
Cost per kg to Mars :	25.0 kUS\$ / kg.

It should be noted that the same models applied on existing space transportation system would give a much higher figure (15 kUS\$ / kg to the Space Station for the US Space Shuttle).

9.4.2.3 Operational Costs

The operational costs are estimated by combining a cost analogy method with a bottom-up approach by adding all the labour and material costs required to complete a yearly operation of the DOCC.

9.4.2.4 Insurance Costs

A very rough estimate of the insurance for space related hardware is estimated to amount to 25% of its recurring value including the launch insurance. This figure depends on the maturity of the technology and the reliability factors of the various components. Therefore, due to technology progress, it can be assumed that these costs will decrease over the next decade. For the operational risks, the insurance costs can not be estimated with accuracy, nevertheless they are expected to represent a significant part of the yearly operational costs.

9.4.3 Costs

This section will summarise the cost details which have been obtained by applying the above methodologies.

9.4.3.1 DOCC Cost Estimates

DOCC Cost Estimates	Terrestrial DOCC (MU\$)	Low Earth Orbit DOCC (MU\$)	Long Duration Mission DOCC (MU\$)
Non-Recurring	50.0	150.0	170.0
Recurring			
•Medical H/W	8.0	35.0	40.0
•Support items (power unit, thermal H/W, etc.)	1.0	9.0	13.0
•Ground Segment	4.0	6.0	7.0
Total	65.0	200.0	230.0

Table 9.4 DOCC Cost Estimates

9.4.3.2 Transportation Estimates

Transportation Estimates	Terrestrial DOCC (MU\$)	Low Earth Orbit DOCC (MU\$)	Long Duration Mission DOCC (MU\$)
Transportation	-	18.0	100.0

Table 9.5 Transportation Estimates

9.4.3.3 Operation Yearly Cost Estimates

Operation Cost Estimates (per year)	Terrestrial DOCC (MUS\$)	Low Earth Orbit DOCC (MUS\$)	Long Duration Mission DOCC (MUS\$)
Pre - flight	1.1	1.6	1.8
In - flight	2.0	3.5 (i)	3.0
Post flight	-	0.5	0.6
Total	3.1	5.6	5.4

(i) the operational costs for LEO operation includes provision for spares and re-supply but no rescue vehicle use.

Table 9.6 Operation Cost Estimates

9.4.3.4 Insurance Cost Estimates

Insurance Cost Estimates	Terrestrial DOCC (MUS\$)	Low Earth Orbit DOCC (MUS\$)	Long Duration Mission DOCC (MUS\$)
Pre launch and launch Insurance	-	12.5	15.0
Operation insurance per year	1.0	1 to 3	1 to 3

Table 9.7 Insurance Cost Estimates

9.4.4 Cost Drivers

In this section, for each cost category, key features which are major contributors to the total cost have been identified.

9.4.4.1 DOCC Items

- *The development costs for designing a fully integrated facility embedded within a wider space system:* All equipment needs to be compliant with the technical requirements (mass, volume, interfacing, etc.). For several items, this means a complete redesign.
- *The development or adaptation costs of high technology medical hardware for space purposes:* All functionalities, performances and reliability factors will have to be checked versus the environmental condition which apply in space (radiation, pressure, etc.). For some equipment, this also implies a significant redesign effort.
- *The recurring costs of high technology items:* The cost of some items is still high because they are new products from recently available technologies. Therefore the market is still too restricted to have allowed mass production and competition.

9.4.4.2 Transportation

The transportation costs have been estimated using the future generation fully reusable transportation systems models which are already much lower than the current figures. Nevertheless, the cost of bringing hardware into space will still remain a major part of the overall cost of any space mission in the next decade, until the space transportation systems reach a mature stage with large production rates and/or volumes.

This has also a secondary effect. As long as the transportation systems will remain expensive for a small mass and volume capacity, a lot of developments are necessary to redesign existing products in order to adapt their physical characteristics to transportation systems. As explained above, this also induces high costs.

9.4.4.3 Ground Control Centre (GCC) and Operation

The major cost drivers have been identified as the staff employed, as well as the equipment acquired and installed in the GCC. Other variables that have significant impact on the cost of operations are the number of “in-flight” users for each DOCC module, as well as the number of DOCC modules being supported by the GCC at a given time.

9.4.4.4 Insurance

The major contributing factors to the cost are the following facts:

- the DOCC is a new product.
- it covers domains with high potential risks such as space and health.
- it involves many international parties in a legal framework which has to be adapted.

9.4.5 Recommendations for Cost Reductions

This section discusses the various possibilities which exist to reduce the cost of the DOCC.

9.4.5.1 DOCC Items

- *Use existing flight hardware.* This would significantly affect the non-recurring effort, but it introduces a risk to lower the integration and optimised concept of the facility.
- *Use existing commercial hardware.* This would significantly decrease the recurring and non-recurring costs, but could eventually affect the optimisation of the concept and could also affect the safety and reliability factors of the DOCC.
- *Use a sequential approach.* As an example, develop a terrestrial DOCC using space concepts at first, validate it for terrestrial applications and then adapt it to space as technology transfer. This would decrease the

non-recurring costs of space DOCC but it would also take a longer lead time.

9.4.5.2 Ground Control Centre (GCC) and Operation

- Design a low cost ground segment which can be run and maintained by a very limited number of specialists (e.g. technicians, doctors).
- Design a low cost ground segment which uses commercial products such as low cost videoconferencing or Internet network capabilities.

9.4.5.3 Insurance

Efforts should be made to distribute the risks and insurance premiums equitably among the various parties.

- Cumulate DOCC insurance with the overall mission insurance (raise the insured volume).
- In case several DOCC's are distributed, adopt a self-insurance policy for the acceptable risks.
- Co-insurance could be negotiated whereby the insurers would be indemnified for only a percentage of any claim, leaving a shared risk among the parties irrespective of their involvement in the damage.
- Governments as insurer of last resort.
- Increase the manufacturers' warranties.

9.5 BUSINESS CONCEPTS

This section provides a conceptual overview of the business interactions regarding the manufacture, marketing, and operation of the DOCC. It assumes that an International Governmental Agreement (IGA) will be developed that will provide a framework by which international space agencies may co-operate in this type of collaborative venture. A sample framework for the DOCC is provided in Section 10.12.

9.5.1 The Pre-Development Phase

As discussed in Section 9.3.2, the development of the DOCC will commence with a Pre-Development Phase, actively led by government organisations working in accordance to the IGA. During this phase, both an assessment study and a design feasibility study will occur. The assessment study should include:

- The establishment of the overall project objectives.
- The development of project requirements and constraints.
- The definition and evaluation of all potential options.
- The performance of trade-off studies.

- The establishment of a reference baseline (such as the “core module” discussed in Chapter 3) and development options (such as the scenarios discussed in Chapters 7 and 8).
- The costing of the reference baseline and the potential options.
- The scheduling and programmatic.
- The identification of critical areas.
- The establishment of a technology development strategy and plan. [Scoon, 1996]

The design feasibility study should include:

- A review and evaluation of the system architectural design and options.
- An evaluation and selection of the system baseline requirements.
- An evaluation and establishment of system constraints.
- The performance of a system design, and the establishment of interface requirements.
- The performance of system/element trade-offs.
- The selection of a reference baseline.
- The performance of a subsystem design and analysis.
- A consolidation of the technology selection and development strategy.
- A consolidation of costs and programmatic. [Scoon, 1996]

Special attention should be focused on the pre-development phase, as its successful completion will provide long-term benefits throughout the life of the project. In particular, the explicit stating of objectives and the early agreement of the baseline reference will minimise conflicts in later stages of the project. A thorough analysis of the design options and their associated costs will provide a level of confidence in the price of development and manufacturing contracts, as well as provide a baseline costing and activity schedule. The fact that the assessment and design feasibility studies occur at a time when costs are lowest in the project further justifies the time and attention they require.

9.5.2 A Design Implementation Model

During the development phase, the IGA will facilitate the contracting of a Prime Contractor from the private sector, by a group of international space agencies. This Prime Contractor is responsible for the manufacture of the “DOCC Space Segment”, as described in Chapter 4, and which is represented by the box in Figure 9.4 labelled “Contract 1”.

The IGA also facilitates the contracting of an organisation (either public or private), who will be responsible for building and providing the DOCC ground

support services, as described in Chapters 5 and 6. This is represented in the box labelled “Contract 2” in Figure 9.4.

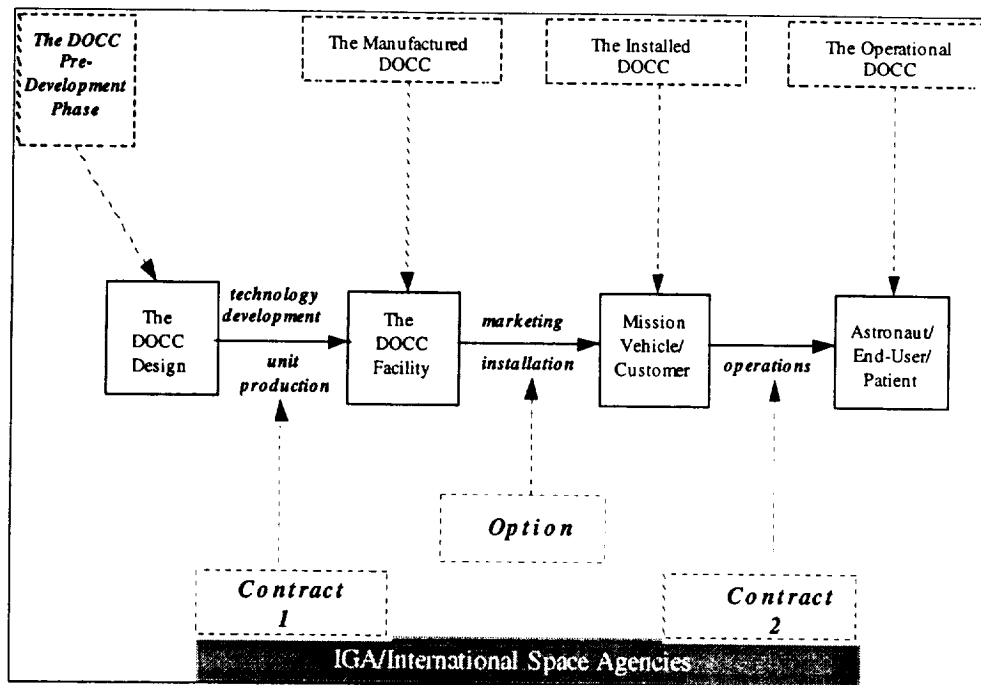


Figure 9.4 Design Implementation Model

The box in Figure 9.4 that is labelled “Option” represents the marketing process of the DOCC system. Section 9.2.5 discusses some recommendations for this function; however, there are several options as to which party could choose to be responsible for marketing the DOCC, including:

- Contractor 1 takes responsibility.
- Contractor 2 takes responsibility.
- Contractors 1 and 2 co-operate.
- A third party is sub-contracted to assume these responsibilities.

Chapter 10 will provide a legal and political perspective on issues such as contracts, intellectual property rights, and technology transfer, which will enhance the model and business concepts developed in this chapter.

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Chapter 10

Political and Legal Issues

The purpose of this chapter is twofold: Sections 10.1 through 10.8 will discuss the political issues regarding the DOCC, while Sections 10.9 through 10.16 will discuss the legal issues regarding the DOCC.

10.1 POLITICAL ISSUES INTRODUCTION

The space field has developed since the end of World War II under the constraints of the threat of mutual destruction. Between 1957-1991, the Cold War created a space race between East and West, for reasons of security, sovereignty and prestige. Space activities provided sources of strategic autonomy and economic power. The first successes in the space race were justified by the necessity to affirm the superiority and prestige of the participants. During these times, political decisions were made for the initial design and construction of launchers and telecommunications, remote sensing, early warning, meteorology, global positioning and navigation systems. Most were designed for defence activities and substantial public funds were not dedicated to other space-related goals.

In the 1970's and 80's, technologies previously developed for military needs found applications in civilian arenas. Spin-offs were spectacular, especially in telecommunications and remote sensing (TV broadcasting and Earth observation). After the collapse of the USSR, in 1991, political reasons to support new space programs became more tenuous. Commercial space activities are competing to survive in a narrow market and public funds are being dedicated to big and costly programs (human flight, space station).

In the future, many nations will probably not be able to undertake ambitious space projects alone. To preserve their capacities and develop their place in international fields, countries increasingly feel the necessity to merge their resources (competence and funds) and to share in the risks and benefits of space exploration. These circumstances are favourable for multinational co-operation efforts as evidenced in the International Space Station and the deep space exploration projects now underway.

Medicine has always been a field of great interest for civilians (general quality of health and life improvement) and for the military (special, war-time survival needs). In this respect, the goals of DOCC present a common interest for these two technical communities. This has resulted in several studies regarding the future of medical advances (see Section 10.2). With the research and development (R & D) and operation of DOCC many of those advances may be very near.

10.2 IMMINENT MEDICAL ADVANCES

The general trend of medical research seems to be exponential. Various studies have indicated that large leaps in the medical field are just on the horizon. For instance, the United States Special Forces Technical Seminar and the Institute for Future Technology in Tokyo have made the following predictions for impending advances in the medical field within the next twenty-five years:

- human sensory enhancement
- broad spectrum immunity to most biological agents
- handheld medical diagnostic equipment
- anti-viral agents for the widespread treatment of viral diseases
- bionic legs, equipped with computer-controlled actuators and small power sources
- cure for cancer
- bionic muscles
- artificial organs from human tissue
- restoration of sight by connecting artificial photoreceptors to the optic nerve
- elucidation of human memory process

While these predictions were made without conducting a wide scale research in a space environment, it would not be unreasonable to consider the applicability of combining current terrestrial research activities with those intended for the DOCC. The result would almost certainly be either significant advancement in a shorter time frame or broader application to more extensive fields of research.

The result of any medical advances developed in the DOCC program will not only have broad social implications, but will also provide significant economic spin-offs that will allow States the flexibility to reallocate resources that would otherwise be spent in the ever-growing health care industry.

10.3 GOVERNMENTAL DECISION MAKING

Ideally, the general role of governments is to have a vision of the future, make good choices, increase the well-being of the people and preserve the interests of their nations. Medicine and health are at the core of the public interests and are subject to decisions regarding the following parameters:

- public opinion
- national economy and potential investment
- strengthening national industry
- decisions of the other States
- benefits and risks of co-operation

10.4 INTERNATIONAL CO-OPERATION

Political challenges have always had and will continue to have an impact on the development of space activities at both national and international levels. It is important to examine the rationale underlying a State's acceptance and funding of major technological undertakings, particularly when they relate to outer space, as this is a sector which poses some very distinctive problems.

It is not difficult to envision the intrinsic value and the various applications of a medical facility such as DOCC. National health care institutions will surely benefit both in the provision of medical care and in the education of their medical practitioners. Moreover, the future of long-term space missions will naturally be dependent on the guarantee of crew safety and health.

In this section, the political reasons governments might want to co-operate with each other and commit public funds to the DOCC project are explored. This is followed by a general discussion of the possible privatisation or commercialisation of the DOCC as a possible political rationale.

10.4.1 General Advantages of Co-operation

- stimulation of national space programs
- access to foreign facilities
- access to new technologies and technical training

- establishment of friendly relations between medical and space communities
- reduction of competition resulting from balanced partnerships

10.4.2 General Disadvantages of Co-operation

- loss of autonomy and sovereignty
- complexity of program management
- possibility of unwanted technology transfer
- possibility of assisting future competitors in the development of scientific competence

10.4.3 Co-operation and the DOCC

The incentives that individual States have for entering into general co-operative agreements are not uniform. With the growing number of practical applications of space activities, conflicts of interest have become more and more apparent. The status of the *Moon Agreement*, for example, demonstrates that even if a consensus is initially reached, it is not necessarily an enduring one.

However, international co-operation has certain indisputable advantages. There are many space projects which are of such technical and financial magnitude that they cannot be realised without tangible international integration. Risk management and allocation is critical to the success of any space venture and international co-operation minimises the risks of the project in that it allows for the sharing of costs. Multi-lateral co-operation also means that the withdrawal of a partner does not necessarily translate into the demise of the project: there are other partners to keep the facility operational. Moreover, a collaborated effort in research and development (R & D) avoids possible redundancy in technological development, and addresses the problem of standards and protocols.

The potential for technology development from one State to another may also provide a sound justification for a State's involvement in a major technological enterprise. In the case of the DOCC, many States may be interested in acquiring medical expertise or the results of technology growth discussed in Section 10.6.3.

In any international co-operative program, the lines of communication must be as open as possible to facilitate the achievement of specific State goals. For example, if one State wants to co-operate for technology growth reasons, this country would need to be honest with the other partners. In doing so, the possible frustration of goals of any partner State will be minimised. This will aid in the efficiency and effectiveness of the DOCC program.

10.5 POLITICAL DECISION-MAKING

The initial use of the DOCC will provide medical support to those involved in the commercial orbital module and the Mars mission on a passive basis.

The DOCC, may in the future, also act as fertile ground to conduct advanced medical R & D which will lead to direct terrestrial medical benefit, or possibly to providing significant spin-off opportunities to other business sectors or markets. This should occur both in the R & D *of* the DOCC and the R & D *with* the DOCC.

While the rest of the DOCC report outlines the design of the DOCC, to fully explore the political and economic ramifications of the facility, the analysis has been taken one step further in this chapter. It is assumed that the decision making process involved in the development and approval of the DOCC will be based upon a full mission scenario to justify significant economic investment by all partner States.

It is likely that the activities of DOCC will lead to developing and improving systems and processes in various fields such as telemedicine and robotics, telecommunications, life support systems, and micro-fabrication. The opportunity to develop new drug compounds in a microgravity environment could also have astounding benefits.

10.6 WHY FUND THE DOCC?

Given the world's current political and economic environment, support and funding for the DOCC from a number of States will only be achieved if the political context of the decision clearly demonstrates wide scale social applicability and, most importantly, overwhelming economic benefit. Additionally, the source of funding and opportunities for cost sharing, not only among international partners, but also among private entities, must be eventually identified.

For a State to commit to and spend money on large-scale space endeavours, it must have justifiable reasons. There are several reasons why a State would be willing to fund (justify the investment to its citizens) the DOCC: international and national prestige (see Section 10.6.1), potential terrestrial applications (see Section 10.6.2), technological development (see Section 10.6.3), possible privatisation or commercialisation (see Section 10.7), and most importantly, ***providing a space medical infrastructure to encourage and facilitate future manned space missions***. By creating a medical infrastructure in space, governments can show citizens they are actively taking responsibility for ensuring crew survivability and success (see Section 10.6.4).

10.6.1 International and National Prestige

It is no secret that the United States went to the Moon in an effort to reclaim its reputation as a leader and respond to the "embarrassment" of *Sputnik*.

President John F. Kennedy's call for a man on the Moon by the end of the 1960's and Neil Armstrong's subsequent walk on the Moon resulted in both national and international prestige. Americans were proud of themselves and their space program. The international community respected the United States and its space program. The United States once again was on top.

To ignore prestige as a viable reason to participate or begin a space endeavour ignores history and ignores its effectiveness as a goal in terms of international power.

There is a certain amount of prestige in being involved in an innovative and necessary project as the DOCC. The DOCC has the potential to make the partner States leaders and innovators in telemedicine, space medicine, pharmaceuticals, and human space travel. Taking a proactive approach to protecting humans in space shows the citizens of the world that the partner States accept the responsibility for the welfare of those humans in space.

10.6.2 Potential Terrestrial Applications

Defending participation in a space program can be easier if a State is able to pledge tangible, earthly applications. The DOCC should have many terrestrial uses. First, countries with large, undeveloped areas such as Canada, Russia, and Australia would benefit from a medical facility designed for remote locations. Second, extreme environments such as submarines, sea-farms, oil platforms, undersea operations, and battlefields would clearly make use of a DOCC facility. Lastly, hospitals, clinics, and medical educational institutions could apply the technologies of the DOCC for day-to-day operation and research.

10.6.3 Technology Development

The unique environment of space requires a high level of technology. In adapting current technology used on earth for space, technology growth inevitably occurs. The increase in technological development may be incremental or exponential; typically, though, one can expect exponential growth. For example, in developing the robotic manipulator arm for the International Space Station, Canada's robotics industry matured to the point of being a primary supplier of technology for automated factories.

Because the DOCC needs to hold the maximum number of medical supplies and equipment in a minimum amount of space, the advances for technology miniaturisation will be incontrovertible. The R & D of the DOCC should do for medical hardware what Sony did for personal stereos (e.g. the Walkman). This would aid in the usefulness of the DOCC (or future versions of the DOCC) in space, in the previously stated terrestrial applications, and in ways that no one can imagine.

Furthermore, the R & D and use of the DOCC should advance the areas of telecommunications, computer hardware, medical software, and pharmaceuticals.

These probable technological growths as a result of the DOCC provide tangible benefits with which States' citizens can relate and support as an acceptable way to spend public money. In addition, the growths will aid in building up industrial capabilities, hopefully gaining the co-operation and support of those affected industries.

10.6.4 Medical Infrastructure for Future Manned Missions

Part of the instability and intrigue of space is the uniqueness of its environment compared to Earth. Humans have evolved so as to survive and thrive in the Earth environment (gravity, oxygen, water). Therefore, to fully explore what space has to offer Earth, human space travellers must be protected.

The *Challenger* accident in 1986 made the United States reconsider and re-evaluate its space program. Is it acceptable to sacrifice human lives for the sake of space exploration? Ten years after that unforgettable accident, space programs continue to explore and adapt ways to make space travel safer.

The DOCC is the next logical step to safe space travel. Safe space travel must include more than the getting there and returning. It must also include maintaining the health and human performance of crews in space. A government should actively protect its own people, whether for an orbiting commercial module, on a Mars mission, or travel to more distant places.

Already in Japan, private industries (Shimizu and Obyashi) are actively pursuing the R & D of orbital and lunar hotels. In this immediate regard, the DOCC will be an indispensable part of that project to assure potential investors and customers of the orbital and lunar hotels' safety and earth-like qualities. This would provide a certain level of comfort and confidence for the weary.

In addition, one must account for general and specific health problems that will naturally occur as a result of having non-professional people in space who are not a part of a specialised selection process

A further political justification for the funding of the R & D of the DOCC project involves countries who may be deciding whether or not to include manned space flight as a part of their space programs. A perfect example is Japan. Should Japan keep the status quo of unmanned space flight or cross the line to manned missions? The loss of a single Japanese life in a manned mission would severely damage the entire Japanese space program, and this is currently a topic of quiet, but intense debate. Having a DOCC would substantially reduce the risk of the loss of life and make the transition, or the

decision to make the transition, to manned space activity a little easier and a little more acceptable [Johnson-Freese, 1996].

Governments who participate in manned space activities are viewed as having the obligation to take precautions in protecting those humans in space. As space missions become more complex and involve longer travel times, the greater the importance of having a DOCC facility. Citizens want to be sure their governments are not actively jeopardising the life and health of citizens sent to space but, indeed, are proactive in their protection. Public opinion is often a driving factor for any national or international program (e.g. environmental conservation). To go further and stay longer in space, the DOCC is an indispensable element of a space medical infrastructure to keep those involved safe, healthy, and alive.

10.7 COMMERCIALISATION OF DOCC

The current movement toward public/private partnerships in space activities will have important implications. Generally, public funds are dedicated to non-commercial activities and private funds are invested by companies using the rules of an open market to develop profitable activities. In fact, that idea is oversimplified and the reality is more complicated. It is often the case that States make the first investments assuming the main risks, and then the private companies develop profitable applications.

For the DOCC, this scenario will most likely provide a funding scheme that will satisfy the political and economic considerations of the partner States. The motivation for financial commitment is linked; public organisations have concern for the well-being of space travellers, and private organisations will provide on-going funding to conduct research on the premise of economic return.

The issue of the potential commercialisation of the DOCC project will not be addressed here from a business point of view. Rather it will be discussed within the context of space policy, as an additional rationale for both governments and private corporations to invest their money in this space medical project.

10.7.1 Economic Interest of Private Sector

From an economic point of view, the interest that private corporations may have in a project such as DOCC would be:

- during the phase of its development, the possibility of getting contracts for the manufacturing of DOCC, and as a consequence of this, getting technology transfers (in the form of patents and free licenses), and possible spin-offs for terrestrial applications.
- during the operational phase, there is the possibility of the DOCC being commercialised on a large-scale, becoming a profitable business, and its

operation being eventually privatised. A large-scale commercialisation within the next twenty-five years (lapse of time envisaged for this DOCC project to be operational), is more likely to happen in remote Earth locations, for an adapted version of DOCC. Nevertheless, there exists the more exciting possibility, the eventual commercialisation of DOCC for human activities in outer space, which should also be considered.

10.7.2 The Development Stage

The DOCC is certainly a cutting-edge technology project. Many existing and innovative technologies will be needed to achieve its full development: telecommunications, medical equipment, computer software and hardware, miniaturisation of electronic components, and new pharmaceutical substances and drugs. The potential for originating new patents, sharing the use of already existing technologies (in the case of international co-operation), and for terrestrial spin-offs, is very high indeed.

The States, thus, may want to spend their money to initiate this project and possibly also share the costs of it through international co-operation. But first, some intellectual property (IP) issues will have to be solved, either by domestic laws or, more probably, by means of an intergovernmental agreement.

Imagine, first, one government funding the DOCC project, and one or more private companies acting as contractors for its manufacturing. In this case, it is important to know what will happen with the new inventions or discoveries made during the development: shall they be the property of the State who puts up the money, or of the company that actually originates the invention or discovery? In this case, one good solution would be that the State get the title on the newly developed patent, not only because it is the main source of funding, but possibly because of the existence of superior public interest reasons, too (i.e. to provide the necessary health care for its citizens in space). The State should be the owner of the patents, but the contractors, as long as they are the builders of the space medical facility, should be allowed free and exclusive license of the patents, both for DOCC and for any other project they may develop in the meantime, in exchange for having actually made the inventions.

What happens with the patents if the development of the DOCC is an international project, with several States equally sharing the cost of R & D? It could be expected, then, that all the concerned States share the benefits of this undertaking, including those technological innovations and inventions obtained, on an equal basis; and as a consequence of this, having joint property of the resulting patents. But, in the case of one of the co-operating States carrying out the most important and costly part of this R & D, another distribution system can be conceived. The major contributing State could get the ownership on the patents, and the rest of the participating States could be given free licensing under certain conditions that would vary, depending on

the amount of their contribution to the project (example: for more or less time).

10.7.3 The Operational Stage

As already discussed in Sections 9.1 and 9.2, it is possible to consider the DOCC as a potentially marketable product, as well as to distinguish several customers who might be interested, in the near future, in a remote medical facility such as DOCC. This possibility must be considered as an additional encouragement or rationale for both public and private entities to invest their money in the development of DOCC.

Can DOCC be privatised, and when? It is not feasible to develop DOCC in a fully private way from the very beginning of the process. The research, the design and the testing of the medical facility would be too costly and too complicated to be made by the private sector alone, without the government providing with some financial aid, guidelines, know-how, and other kinds of support. Instead, it is more reasonable to expect that one government (or several governments) will be the main contributor involved in this development phase. The only exception would be some corporations acting as primary contractors for the government. The countries more interested in funding and leading the project would be, logically, those carrying out manned space activities.

After a preliminary phase of exclusive (or almost) governmental involvement, then the private sector could also gradually become involved in the project, especially during the operational phase. As soon as the commercialisation of the DOCC becomes feasible, the participating governments can begin thinking of its privatisation.

In today's world, many space activities are shifting more and more towards the private sector, for a number of reasons: ideological, efficiency, complexity. The three main fields of private involvement in space, so far, are launch systems, telecommunication satellites, and remote sensing services. The DOCC or any other remote health care system in space could, in time, follow the same path, as long as its commercialisation can turn it into a self-sustaining activity as well.

In this sense, one can consider the analogy with the Ariane launcher. The Ariane was developed on an intergovernmental basis by a group of European countries, for purely "public interest" reasons (they wanted to have a European independent access to Earth's orbit). As soon as this first strategic rationale was achieved and consolidated, the public interest declined in favour of a more commercial rationale. The growing market of commercial space launchers and the increasing number of customers for it, made the space launching activity a profitable one. Thus, the European Space Agency decided to privatise the Ariane launcher, and a consortium of European companies to run this activity, Arianespace, was incorporated.

In the case of the DOCC project, the question is whether a potential market exists for it in a foreseeable future, so that one may consider its commercialisation and eventual privatisation. To answer this question, two possible approaches will be briefly examined: terrestrial applications and space applications.

Terrestrial applications are more likely to exist in the near future. The extensive medical and technical research necessary to develop the DOCC project may have enormous applications for Earth's telemedicine and remote health care in general, many of them of commercial interest. Therefore, those companies currently working in the field of telemedicine (either as equipment manufacturers, or as telecom service providers) may well be interested in participating in the R & D of DOCC. Also, remote medical facilities that are adaptations of the DOCC, could be used to provide adequate health care for a wide range of remote locations on Earth: rural settlements, submarines, polar bases, off-shore oil platforms, battlefields, and co-operative agricultural units. They could also be used extensively, in the field of international telemedicine, to overcome the lack of specialists in the hospitals of developing countries. Even in developed countries, they could be useful as a tool for mobile emergency treatment (e.g. ambulances).

Concerning space applications, they are not likely in a near future. Neither of the two mission scenarios considered in this report (a mission to Mars, a orbital scientific facility) allows for real commercialisation. In the further future, nevertheless, one can foresee an increase in manned space activities, and therefore, an increase in the needs for adequate health care for a great number of people in space (as would be the case for the "well-known" possibility of massive space tourism and orbital hotels). When these possibilities come true, then the DOCC, in the way it has been envisaged here, will be successfully commercialised.

10.8 ADMINISTRATION

Once the DOCC project obtains political and economic support, details regarding the administration of the facility will be outlined in an Intergovernmental Agreement (IGA). A sample framework is outlined in Section 10.12. However, an important aspect of the agreement will focus on determining the access to, and the use allocation of the facility. As previously stated, it is assumed that a DOCC will not only provide the facilities to maintain the health and well being of humans in a space environment, but will also provide the capability to conduct numerous R & D activities. Per the 1968 Rescue Agreement adopted by the United Nations General Assembly, it is the general duties of States to render assistance to astronauts in distress. Co-operation between all States must be assured with a view to the effective conduct of search and rescue operations.

Therefore, a DOCC would be open to any State requiring assistance in providing health care to all astronauts, especially when critical care is required to save the life of any space traveller in a state of duress or the

victim of an accident. In emergency situations, critical care will not be dependent upon whether a State is a formal partner in the IGA for the development and operation of a DOCC; rather, the primary requisite for critical care will be based upon need. However, the owner of the DOCC *will* be charged on a “subscription” basis for the ground/service segment and it is expected that this cost will be passed on to the using State, individual, or corporation (see Chapter 9).

10.8.1 Allocation of Use

With respect to maintaining the general health of astronauts and conducting various R & D activities, guidelines would be developed as part of the IGA which would outline the use and time allocated to the member States ratifying the agreement. The agreement regarding the use of the DOCC would be based on a consensus of all participants.

In comparison to the International Space Station’s Intergovernmental Agreement (ISS IGA), the allocation of time for the DOCC would most likely be reflective of the general principle that the majority investor in the venture would also be the majority shareholder in the utilisation of the facility [Meredith, 1992]. Given this assumption, States with the greatest interest, combined with a political structure which supported the resources required to bring the project to fruition, would have the greatest power in leveraging the allocation of time and facility resources for their own use.

10.8.2 Discretion of Use: Public/Private Entities

Once time and use have been allocated among all participants, member States will then have unlimited discretion to allocate resources between public and private entities within their own State as long as the intended activities promote the peaceful uses as outlined in the Outer Space Treaty of 1967. It is anticipated that individual States would allocate time and resources between public and private entities based on the scientific value and the economic benefit of the proposed activities. Certainly, political pressures would dictate the allocation of time for R & D activities.

10.9 LEGAL ISSUES INTRODUCTION

The design, development and implementation of a DOCC must be governed by the existing body of rules, policies and procedures which have come to be known as International Space Law. As the exploration and use of outer space become more and more sophisticated, the international legal framework which underlies such activities must also mature. One must ensure that new space ventures, such as the DOCC, abide by the principles outlined in the various United Nations (UN) treaties.

In this section, the Outer Space Treaty and the Rescue of Astronauts Treaty are analysed. This is followed by a look at what should be covered in an IGA for the DOCC. The last part of this chapter includes a discussion on IP rights,

privacy and liability issues, and the foreseen role of the World Health Organisation.

10.10 THE OUTER SPACE TREATY

The 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (also known as the Outer Space Treaty, hereinafter “OST”) recognises the common interest of all mankind in the progress of the exploration and use of outer space for peaceful purposes. It aims to promote broad international co-operation in both the scientific and legal aspects of outer space exploration. This Treaty sets out the fundamental principle of non-appropriation: outer space is to remain the “province of all mankind.” In this context, the architects of DOCC should be mindful of all aspects relating to facility access and co-operation. It also states that astronauts must be considered envoys of humankind in outer space and that parties to the Treaty shall render to them all possible assistance in the event of an accident, distress or emergency landing. This general principle is further developed in the 1968 Rescue Agreement.

Given that DOCC will provide facilities for both privately and publicly funded research, it is imperative that partner States are fully cognisant of their responsibilities under international law. The 1972 Liability Convention elaborates on the general liability principle set out in the Outer Space Treaty. The principle of international co-operation and consultation set out in Article XI is of particular significance to a project such as this one. Related matters covered by the Convention such as the equality of partner States with respect to access to information on various national space activities are also relevant with respect to the exchange of data between DOCC partner States and third-party States.

The DOCC, developed by a host of international partners, must embody the full intent of the basic principles set forth in the OST. Specifically, the development of the DOCC for an orbiting facility or for a Mars base would require an undertaking of international proportions given today’s political environment. As most nations are experiencing fiscal crises, many national or regional space programs are not able to compete as successfully for limited resources as they have in recent years against programs aimed at broader social objectives. It is not unlikely that future large scale space initiatives such as the DOCC will require a number of international partners, acting in a spirit of co-operation with the aim of accomplishing a number of common goals.

With the anticipated growth of human activity in space, and with missions extending for longer periods, it is essential that medical facilities and comprehensive care procedures are developed to assure the health and safety of future flight crews. These facilities would not only provide basic medical care for space travellers, but also a base in which to conduct medical R & D with application to the terrestrial environment. The outcomes of advancing

medical science contain no boundaries; all of mankind would benefit from the extension of medical practices, procedures and advances in promoting the health and well being of all peoples, regardless of citizenship.

10.11 THE RESCUE AGREEMENT

The 1968 *Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched Into Outer Space* seeks to develop and give expression to the general duty of States to render assistance to astronauts in distress. The Agreement states that each contracting State receiving any information or discovering any personnel in distress must immediately notify the UN as well as the launching authority. Both States must co-operate with a view to the effective conduct of the ensuing search and rescue operations. These operations will be subject to the direction and control of the State on whose territory the spacecraft makes its landing. Articles 3 and 4 address the situation where information is received about personnel of a spacecraft alighting on the high seas or in any other place not under the jurisdiction of any State. It would seem from the wording of the *Agreement* that the DOCC partner States would be responsible for extending assistance to space travellers of other States who are in distress. Those Parties which are in a position to do so shall extend assistance in search and rescue operations as well as inform the UN and the relevant launching authority. Certainly, a medical facility in space would have the capability of treating space travellers who may have been injured and need emergency treatment. With the DOCC in outer space, it would no longer be a requirement that situations involving critical care would rely on terrestrial comprehensive treatment where the transportation alone could prove to be fatal. At the very least, the DOCC would ensure the stabilisation of an accident victim. Taken to its full potential, the medical facility would provide the necessary tools to assist in the full recovery of a patient in a space environment.

10.12 A SAMPLE FRAMEWORK

While various treaties and agreements ratified by the United Nations General Assembly provide a basic framework for conducting space activities, specific activities between international partners are detailed by individual co-operative agreements. General principles, guidelines and procedures regarding the design, development, implementation and operation of a DOCC outlined in an IGA would provide a foundation for decision making. IGA's do not have to be comprehensive or exhaustive; "they are merely intended to provide a starting point or initial framework which may be expanded, reduced, modified or discarded in favour of better or more agreeable alternatives that negotiators or drafters deem appropriate in light of existing conditions or circumstances" [Grove 1991]. Some of the more substantive provisions which an international agreement on the R & D of a DOCC might include are:

- A) **Introductory Provisions**: outlines the basic preamble and contains the mission statement
- B) **Objectives and Purposes**: details driving factors on the rationale for a DOCC
- C) **Contacts and Co-operative Activities**: guidelines for the exchange of information, personnel, policies, practices, regulations, and co-ordination of joint projects and research activities
- D) **Exchange of Information**: provides a framework on how information will be exchanged and how it will be used
- E) **Implementation**: provides the framework for administrative arrangements, detailed procedures, and establishes a joint committee for implementing the agreement
- F) **Availability of Funds**: provides that participation in the agreement will be subject to the availability of appropriations in accordance with the legal processes of the government of the party
- G) **Costs**: confirms that each State or participating institution, organisation or firm will bear the costs of its own participation
- H) **Force Majeure**: provides provisions for suspending the responsibilities of the parties due to events not within the control of any party
- I) **Applicability of Domestic Laws**: provides that parties will agree to respect the laws of other parties, including protection of proprietary data and rights of intellectual property
- J) **Closing Provisions**: outlines period of performance and ratification process
- K) **Annex**: may contain special provisions relating to patents and inventions

[Grove 1991]

The above outline is “intended to serve as a starting point for the drafting or elaboration of an initial framework for international co-operation” [Grove 1991]. As circumstances dictate, the provisions of an IGA for developing a DOCC will depend upon the negotiation of all interested parties. Co-operative agreements must be flexible in their language to provide for the unique characteristics and objectives of each space activity undertaken by a number of international partners. Through negotiation, a consensus will develop which will reflect the driving forces, objectives and desires of all parties which have ratified the agreement.

10.13 INTELLECTUAL PROPERTY

As the use of outer space increases, so does the opportunity of new discoveries and inventions. In the international co-operative environment of today, the impact of different intellectual property (IP) laws is significant. This section will deal primarily with the different patent systems, how they can affect the R & D of the DOCC, and the implications of using the DOCC

for R & D purposes. The DOCC, as a medical facility, has the potential to be a medium for medical discoveries and experiments, necessitating a discussion of the DOCC's IP implications.

10.13.1 “First-to-File”

The patent system used by most major States, except the United States (U.S.), is the “first-to-file” system [Vision 2020, 1995]. When an invention, discovery, or new procedure is to be patented, the inventor must be the first person to file with the patent office and must not make any public disclosures regarding the invention or discovery prior to filing [ESA, 1994]. Because of this system, if a communication between a DOCC user and a terrestrial receiving station is intercepted, a patent right may be at risk.

10.13.2 “First-to-Invent”

The U.S. uses a completely different patent system: the “first-to-invent” system. If one is the first to invent or discover “any new and useful process, machine, manufacture or composition matter, or any new and useful improvement thereof,” he/she qualifies for a patent [Reynolds, Merges, 1989]. To be considered an invention, it must be more than a simple extension of what was known from the prior art (i.e. the discovery must be novel). Unlike the European system, the U.S. system allows for a one year grace period before filing [Reynolds, Merges, 1989].

10.13.3 Infringement of Patent Rights

Because of the conflicting patent laws of potential partner States, it may not always be obvious when one is violating a patent right of another. This becomes increasingly important when it is time to commercialise the DOCC. Private and industrial investment and use (particularly in regard to the low earth orbit, commercial module) will depend on appropriate legal protection from IP infringement [ESA, 1994].

A company may use the invention or discovery of another if the latter company is using it for an experimental purpose or use. The term “experiment use” is a potential source of confusion for private entities and will need to be defined. If not satisfactorily defined, inadequate private participation may be a possibility. The potential cost of infringing on another's IP rights may prove too great a monetary risk in addition to the already tremendous costs of space [ESA, 1994].

The potential monetary risk is important if a private entity accidentally or purposefully uses the invention or discovery of a competing private entity in the R & D *of* the DOCC. Does the latter entity have to pay the former for the infringement or does it fall under experimentation? What if the same thing happens in R & D *with* the DOCC in space? Basically, the latter scenario will be solved by existing case law. For the former, the solution will be

determined by the agreement of the States involved in the assumed missions--not the manufacturer of the DOCC.

10.13.4 Recommendations

The problem of co-ordinating the different systems in space has been identified via the ISS IGA. Since the DOCC is intended to be placed in a commercial orbital module, on a Mars transfer vehicle, and on a Mars base, the nationality (thus the applicable patent system) can be determined by the owner of the facility, vehicle, and/or base. Once again, the individual member States will determine this in the mission agreements.

However, the ISS IGA is a logical place to look for a foundation on which to base some conclusion. For example, according to Art. 6, para. 6 of the IGA, "the ownership of equipment or materials provided by a user shall not be affected by the mere presence of such equipment or material in or on the Space Station." If a State owns certain equipment that was used to create patentable material (on the commercial orbital module), that State does not have automatic ownership of the material. So, despite *who* builds the DOCC, the patent rights of the DOCC's ultimate users cannot be affected, unless those users otherwise agree [Tatsuzawa, 1992].

Furthermore, Art. 21, para. 1 and 2 of the ISS IGA mandates that "for the purpose of [IP] law, an activity in or on a space station flight element shall be deemed to have occurred only in the territory of the Partner State of that element's registry" [Tatsuzawa, 1992]. Following this guideline, the DOCC used for either of the mission scenarios will follow the patent system of the State who registers the module, vehicle or base.

10.14 PRIVACY

The individual's right of privacy is, definitely, one of the most important legal-ethical issues to be considered when implementing a project of distant health care, whether this project is undertaken on Earth or, as it is the case with the DOCC, in outer space. With DOCC, the issue of the protection of privacy has two main aspects: the confidentiality of medical personal data transmissions, and the confidentiality of stored patient records.

10.14.1 The Distant Health Care and the Right of Privacy

In the relationship between doctor and patient, which is the relationship that normally arises when both of them meet physically (or interact remotely, in the case of telemedicine), it is universally accepted that every patient is entitled to have his privacy protected. It is part of the obligations of the physician to respect this right, as it is recognised by the Hippocratic Oath and by most of the domestic laws currently regulating this relationship. The private information of the patient has to be respected by the doctor (obligation of non-disclosure), and also must be kept apart from any other person who is outside the above mentioned relationship.

Now that the first telemedicine programs are being carried out in several countries, protecting patient privacy has become a topic of significant debate. The main point of concern arises out of the fact that in all of these programs, all the patient information is to be collected and stored in electronic format rather than on paper.

Some people have suggested that electronically stored information is more susceptible to unauthorised access. Conversely, others suggest that properly designed electronic security systems can be more secure than those currently used to protect the traditional paper patient record [J. Reid, 1996].

When implementing the project of the DOCC, this issue will have to be somehow addressed. Certainly the astronauts participating in the two mission scenarios envisaged here will be professional (or semi-professional) astronauts, and therefore they can see their rights of privacy restricted to a certain extent, because of scientific-medical reasons. But even in this case, the most personal medical data generated by the astronauts are very likely to be kept confidential from anybody apart from the mission operators.

Possibly, one day a great number of non-professional astronauts will fly into space (as would be the case, for instance, for massive space tourism to an orbital or lunar hotel), and then the DOCC, or any other remote health care project, will be operated on a large scale, in order to provide these people with appropriate medical assistance. In this case, the issue of the protection of the latter's full rights of privacy will surely be raised and will have to be solved by the space lawyers (or judges), in a more complete and definite manner than the way it is dealt with herein.

10.14.2 Space Law and the Right of Privacy

According to Article 1 of the OST (1967), the States' parties agree to carry out the space activities in accordance to the International Law.

Article 12 of the Universal Declaration of Human Rights (1949) establishes that: "No one shall be subjected to arbitrary interference with his privacy, family, home or correspondence... Everyone has the right to the protection of the law against such interference or attacks".

The Universal Declaration of Human Rights is an important part of the International Law. Therefore, there is ground on which to defend the existence of a commitment from all the States which are parties to the OST to carry out their activities in space with respect to individual's privacy as well as to all the other human rights. And one must not forget either that the right of privacy thereby stated, is also included in the national constitutions of almost all the States carrying out space activities. This statement is true, whether in the case of astronauts being full or semi-professionals (as it happens in the two missions envisaged in this report), or non-professionals (as it would be the case for scientists, journalists, tourists...).

In the future, however, an amendment of the international Agreement on the Rescue of Astronauts (1968) could also be considered, in order to revise their traditional status as “envoys of mankind” and to more specifically recognise for them this particular right of the individual.

10.14.3 Restrictions on the Right of Privacy of Professional Astronauts

Notwithstanding what has just been said, the fact that professional astronauts are expected to work in the two mission scenarios of the DOCC project has the implication that probably the right of privacy of the individuals will undergo some restrictions.

In the case of a mission to Mars, there is no doubt that complete privacy of the persons involved will be very difficult, if not impossible, to guarantee. The characteristics of such an undertaking are so exceptional that the astronauts would be, for sure, in the aim of all the press and other mass media world-wide. Of course, the ground segment operating the mission would be able to screen part of the information (for instance, the medical information) before it is released to the media. But still the curiosity of the public opinion would be so strong in the case of a Martian endeavour, that it is not believed that any of the astronauts could ever have even a cold, without the whole world knowing it. For reasons of publicity of the mission, then, one can expect a minimum confidentiality of the personal data of the astronauts. One could also conceive the opposite situation, though: a Martian mission carried out in a secret, military-like way, where the top leaders of the project would not allow any sign of weakness of the crew becoming of public knowledge. This is not a situation admissible in the world of 1996, but in 2020, who knows?

What may be the most important aspect to consider in the case of a Martian mission, is that these astronauts clearly would be passing through a unique experience in terms of prolonged exposure to the space environment. To fully study the way they respond to this experience would be of the utmost importance for the advancement of space medicine. Thus, it is reasonable to expect a serious restriction in the confidentiality of their medical records, if only for scientific and medical purposes. There is still not enough information about the effects of a long space travel on the human body, and therefore it is essential that the medical data are disseminated as widely as possible for further study by space doctors. The tension here between the individual's rights and the community's scientific interest will initially be solved in favour of the latter. This assertion is coherent with the principle embodied in the 1967 OST of utilising the space to advance the knowledge of mankind.

Finally, the fact that these astronauts will be so far from the Earth makes them much more dependent on telemedicine to solve many of their health troubles. Again, this is a reason to believe that they would be willing to allow part of their right of privacy to be restricted under the presence of more important interests (in this case, the preservation of their own lives).

Then there is the second scenario, that of an orbital commercial facility for scientific experiments, dependent or somehow related to the ISS. The astronauts involved in it could be semi-professionals, not submitted to such a rigid discipline and rules, and such following of the mass media, as the astronauts going in a Mars mission would surely be. They would also be less dependent on telemedicine than the latter. For the most serious health troubles, they could be sent back to Earth immediately (see Section 7.2.6). Also, their working environment, LEO, is not as exotic in terms of scientific-medical studies as a Mars mission environment. For all these reasons, these astronauts will not be so willing to give up their full rights of privacy as in the case of the Mars scenario. They would surely expect full confidentiality of their medical records and data, at least from everybody outside the space agency or corporation that has hired them.

In both mission scenarios, it is reasonable to expect that the astronauts will have their privacy issues regulated through their labour contracts with the space agency or corporation that sent them there. This problem will be tackled again when liability issues are discussed in Section 10.15.

10.14.4 How to Secure the Confidentiality of Personal Data

Once it is agreed that the DOCC project must protect the right of privacy of the individuals involved in it, the logical corollary of this is to make a review of the practical ways that exist to secure the confidentiality of the personal data. To do this, the three segments to be considered in the normal operation of a remote medical facility providing care in space will be distinguished.

- A) **Protection of the Data Aboard the Spacecraft.** Provisions should be made so that, when somebody inside the spaceship makes use of the DOCC facility, the rest of the crew members do not learn the personal information that may arise during the teleconsultation or health care delivery. To achieve this, the DOCC space module could somehow be placed physically separate from the rest of the spaceship (in an especially reserved area, for instance). The encryption of the data and the authentication methods (see B, below) would also guarantee the privacy at this stage of the project.
- B) **Protection of the Data during the Transmission (Encryption).** For this particular step, which is an essential part of any space telemedicine project like DOCC, the general opinion is that some kind of encryption (or “scrambling”) of the data should be made, in order to prevent any person outside the mission from obtaining the data and perhaps making illegal use of them.

Within the section of this report devoted to “Data Handling and Communications” (see Section 4.2.3), the technical details concerning the codification of the signals sent to and from the Earth have been discussed. Basically, the encryption of the data for confidentiality purposes in a telemedicine project, such as DOCC, may not be fully

possible right now, but will be possible with the software to be developed in the near future.

In the aforementioned chapter, the possibility of further protection of the transmissions through the use of authentication methods (such as passwords) has been suggested.

Finally, several levels of encryption could be used during the regular operation of the DOCC facilities, utilising less intensive methods for the bigger part of the operations (routine monitoring, routine literature consultations), and reserving the most intensive encryption methods for the “sensible” information (the personal information that may arise in teleconsultations and general telemedicine).

- C) **Protection of the Data on Earth** (and in space, if the personal data are also to be stored in the spacecraft). Adequate safeguards should be put in place by those who manage the electronic databases of medical information.

The privacy of the patient requires securing the confidentiality of the stored information, by means of a restricted access to the medical databases. This way, any inappropriate use of the records may be prevented. One must consider those methods for protection which can provide: (1) confidentiality (by avoiding inappropriate access to any component of the medical record), (2) availability (by having the record easily available to those who are duly authorised to access it), and (3) integrity (by having it correctly entered and updated over time). Again, authentication methods seem to be the most suitable ones to achieve this aim.

To conclude with the issue of privacy, it is clear that those persons (individuals and institutions, care providers or third parties) who may be found to mismanage or to misuse any patient medical information, should be held civil or criminally liable from these actions.

10.15 LIABILITY ISSUES

10.15.1 Telemedicine and Liability

The DOCC project is intended to provide health care remotely to a group of astronauts during their stay in LEO, or during a flight to Mars. In its basic conception, one can observe that the DOCC project shares many of its characteristics with the most advanced telemedicine projects that are currently being undertaken in order to provide health care to remote locations on Earth (such as in rural areas and battlefields).

For this reason, the legal studies that are currently being made concerning the liability issues that may arise from the general practice of telemedicine, can be considered a good starting point for analysing the DOCC project and its possible consequences in terms of liability.

Notwithstanding the above, one must admit that the current situation of the liability analysis is far from perfect concerning earthly telemedicine (let alone space telemedicine). Some guidelines will be offered here on which future studies, both for earthly and for space purposes, could be made. But it is fair to warn everybody that there are no definite approaches to some liability issues, and will be none until some kind of precedent is set. Liability issues in both Earth-based and space-based telemedicine, at the end, will have to be solved on a case by case basis.

A good start for this work is accepting the general principle that telemedicine is not a new medical discipline, but rather a new way of doing the same old things [J. Reid, 1996]. As a consequence, many of the existing practices, policies and standards of health care should apply to this new domain.

Telemedicine simply takes advantage of the new telecommunications and information technologies (voice transmission, text and images transmission, video-conferencing, computers, virtual reality) to monitor, prevent and diagnose medical conditions.

Telemedicine also allows the electronic transmission of the patient's record and patient's test results. These transmissions have implications not only for the right of privacy of the patient (as seen in Section 10.14), but also in terms of originating a bigger liability on the part of the distant care provider, as discussed in Section 10.15.2.2.

Another issue to be determined in the future is whether or not the use of telemedicine technology introduces an additional degree of risk into the practice of medicine. Would the interruption of a teleconsult due to equipment failure, the use of encryption or of data compression schemes that lose some of the original data, or the distortion of colour in transmitted images, increase the risk of liability for the parties involved in this medical relationship? As part of the answer one can mention that, since the risk of malpractice is bigger in telemedicine, the hardware will be more extensively tested to prevent any failure. Another partial solution is the waiver of liability from the employees involved in those telemedicine projects conducted for their own benefit by a national agency or by a private corporation.

10.15.2 Liability of the Parties Involved in DOCC

10.15.2.1 Liability of the Astronauts aboard the Spacecraft

In the case of liability on the part of the primary care provider, or medical officer on board, arising out of medical malpractice, it can be argued that the space agencies or corporations that have hired the astronauts are, at the end, responsible for all the actions carried out by them. Also, in a space mission where all the astronauts involved are professionals, it is reasonable to expect that liability issues among crew members, and between the astronauts and their employing agency, will be solved by means of the usual waiver clauses

and assumption of risks clauses, to be included within the labour contracts of these persons.

Of course, one can conceive the application of the traditional rules for determining negligence, as in Anglo-American Law there is the rule of the “reasonable man” (“what would a reasonable doctor do on a trip to Mars?!”). But, only in those cases of very unreasonable or extremely negligent behaviour, would it be possible to claim for damages directly from the primary care provider who has travelled aboard the spaceship. For most of the cases, the risks will surely be assumed by the space agency/corporation and will be accepted by the professional astronauts involved in the mission.

10.15.2.2 Liability of the Consulting Physician

When examining the issue of the liability of the consulting physician, one can arrive at the most interesting but also the most difficult aspect of liability in telemedicine.

The first point to deal with relates to the establishment of a physician-patient relationship. Is this relationship validly established in telemedicine? To make it short: definitely, one can answer yes.

Unlike a routine telephone consult (sic), during which one provider may discuss a patient in general terms with a colleague, the richness and depth of information exchanged during virtually any telemedicine consult is adequate enough to assure that a physician-patient relationship is established [J. Reid, 1996].

The most accepted opinion in hospitals today is that, during teleconsultations, the patient’s care remains under the control of the primary doctor, and that the specialist (consulting) doctor incurs no significant risk with it. But, again, the consulting physician in a telemedicine consultation will often receive far more, and more accurate information upon which to base his or her opinion: he will be able to visualise the patient’s physical state through X-rays, pictures, or ECG’s, will hear the patient’s body organ sounds, will see the aspect of the patient, and will even interact with him in real time to ask him some specific historical questions. From this point of view, it is possible to defend the existence of responsibility, and therefore potential liability in cases of medical malpractice (e.g. erroneous diagnosis), on the part of the consulting doctor.

Even if one considers this problem solved, that is only the beginning. Many other related issues arise, and still remain to be settled. Imagine the case of an American doctor making a mistake during a DOCC teleconsultation, as a result of which a Russian cosmonaut falls severely ill. This case presents many issues, such as: is there more degree of liability for the consultant in interactive telemedicine than when all he does is review a patient’s case and then give his professional opinion? One can think that it is logical this way, but will it always be so?

Another related problem is: do the professional liability insurance policies cover the practice of space telemedicine by the doctors? Will doctors practising space telemedicine be required to have a special (international) licence? If so, who will be in charge of regulating it, giving and retiring it to the doctors, and what will be the consequences of unlawful actions such as working without licence? It has been suggested that, in telemedicine interactions, the patient should be considered as travelling to the physician rather than the other way round: this means that for every consulting doctor, it is his or her State authorities who have all the regulatory and disciplinary power. This solves the licence issue, but the solution is bad for the patient if, in case of malpractice, he has the additional burden of having to travel to the consulting doctor's country, to file and execute a complaint or lawsuit against the liable physician. The national medical associations and, in the case of DOCC, the IGA or any other specific agreement, will have to address all these telemedicine issues in a manner that is convenient for both the medical practitioners and the patients.

10.15.2.3 Manufacturer's Liability

Of course, liability arising out of failures in the telemedicine equipment must also be considered. Imagine, for instance, a piece of DOCC equipment made in Russia malfunctioning and, as a result, an American astronaut is injured. These cases are far easier to solve than the two cases discussed above. Undue failures of the DOCC equipment because of manufacturing defects, imply the manufacturer's liability; the manufacturer most likely being a private company acting as a contractor for that space agency or corporation who is responsible for the mission. The possibility and the consequences of this kind of liability, in such complex missions as the ones considered here, will surely have been thoroughly foreseen and regulated within the manufacturing contracts of the DOCC facilities. The same is true for the case of a (relative) mass-production of these remote medical facilities, as the term "modular" (included in the definition of DOCC; see Introduction chapter) seems to imply. In both cases, one can also expect extensive tests of performance being made, before the equipment is actually used, in order to minimise the manufacturer's liability.

10.15.2.4 Operator's Liability

One can also conceive of cases of DOCC malfunctioning because of mistakes in the purely operational segment: negligent interruptions of the telecommunications link of the spaceship with the ground control, erroneous commands sent to the spaceship, unjustified delays in connecting the facility with the consulting physician, or any other error as a result of which, the health condition of any of the astronauts gets worse.

If the operation of the remote medical facility is carried out by the own space agency, then the consequences of personnel negligent actions will probably be settled by purely internal procedures: settlement of new rules of operation or disciplinary measures towards the particular individual responsible for the failed operation. But if a private company were running all the DOCC space

medical facilities, as a contractor for the main space agency or corporation responsible for the mission, then again it is reasonable to expect that the possible consequences and the possible compensation arising out of this negligence will have been foreseen and regulated on an extensive basis by both parties involved in the DOCC project implementation.

Of course, failures in the operation of DOCC due to force majeure (the so-called acts of god, for instance, a solar flare interrupting the telecommunications link of DOCC with Earth) will not arouse anybody's liability, unless it is combined with any gross negligence from any of them.

10.15.2.5 Concurrent Liability

When failure of DOCC to provide the necessary health care is not clearly due to any of the above described persons, or it is openly due to several causes, how will the issue be solved?

One can easily predict that, in every telemedicine malpractice claim, at least in terrestrial telemedicine cases, every person who has anything to do with the case, from the physicians to the equipment manufacturers and to the telecommunications services providers, are likely to be named before the court. But there are no clear rules for that. Each case will be different, and responsibility will vary according to the nature of the malfunctioning or malpractice allegation.

In case of space telemedicine, again one can expect for this case the setting of cross-waivers of liability, clauses of joint assumption of risks, and some other rules, by means of contractual clauses among the several persons involved in the project.

10.15.3 Liability Issues Conclusion

The potential liability issues concerning a space project such as the DOCC can be easily foreseen as an extension of the general telemedicine liability issues, and also some solutions can be proposed. But the exact solution to these issues can not be delivered yet, simply because it does not exist. Most likely they will have to be settled in the future on a case by case basis, either by means of contractual waiver clauses, or by means of jurisprudence.

10.16 WORLD HEALTH ORGANISATION

The Constitution of the World Health Organisation (WHO) was adopted on 22 July 1946 by the International Health Conference, convened by the Economic and Social Council of the United Nations. WHO was created on 7 April 1948 when the 26th UN member ratified the Constitution.

Broadly speaking, the objective of WHO is the attainment by all peoples of the highest possible level of health. "Health" is defined in the WHO constitution as a state of complete physical, mental and social well-being and

not merely the absence of disease and infirmity. In the aim of attaining these goals, the Organisation has a wide range of functions. It may be interesting to examine these functions in relation to the organisation and development of the DOCC project. For example, the WHO's mandates include:

- the promotion of technical co-operation;
- the provision of appropriate technical assistance (upon the request or acceptance of Governments);
- the promotion and co-ordination of biomedical and health services research;
- the promotion of improved standards of teaching and training in the health, medical and related professions;
- the establishment of international standards for biological, pharmaceutical and similar products, and to standardise diagnostic procedures;
- the proposal of conventions, agreements and regulations.

Any international project focused on medical care and research, should work in collaboration with WHO to identify available national and external resources including those of existing WHO programmes. The expertise and experience of such an organisation may prove to be invaluable to the international players involved. In the establishment of management strategies and work plans for the DOCC facility, WHO could act in an international advisory capacity. Its primary function would relate to the standardisation of operating procedures and to the issue of co-operation between partner States in the domain of health care and medical research.

The IGA which will support the activities to develop the DOCC, as discussed in Section 10.12, will have one main objective: to promote the health and well-being of professional and non-professional space travellers as well as civilians around the globe. In this context, it will act in the spirit of the World Health Organisation and stimulate international co-operation in technical and scientific fields. This includes the creation of standards in training, equipment, and pharmaceuticals. The DOCC will serve to reduce inequalities in access to health care and education: terrestrial applications of the DOCC will facilitate medical consultation with specialists from remote locations. Moreover, the transfer of medical technology and knowledge will be promoted in a co-operative atmosphere: for example, special attention must be given to developing countries in the provision of high quality health care where there is a lack of adequate equipment and expertise.

It must be noted that with the participation of a great number of States in the DOCC facility, questions relating to certification of medical care providers and equipment will arise. Many nations have different procedures for educating and certifying their medical doctors. There is a need for global consistency in medical training and in medical protocols. The DOCC project

may be the ideal forum in which to address such issues. For example, the IGA supporting the DOCC could include a process by which standards will be established: a subcommittee could be set up to examine such questions. Its mandate would be to develop proposals in consultation with the World Health Organisation, proposals which would eventually be voted upon by the Consortium members.

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Section V

Conclusions

Chapter 11

DOCC Project Risk Assessment

This chapter will identify and discuss the risks associated with the overall DOCC Design Project. It will also rank the perceived severity of the risk, and will suggest actions which will minimise the risk.

11.1 DESIGN AND ARCHITECTURE OF MODULARITY AND ADAPTABILITY

In the mission statement, the design project team assumed that the DOCC shall be a modular facility which will be adaptable to a range of remote human habitats. This statement led the research, design and architecture process of the Design Project in a specific direction. Additionally, the team decided to focus on the design of the medical facilities rather than the design of the whole mission including transportation and rescue vehicles, base habitats or LEO stations.

The chosen approach for the entire DOCC Design Project is dependant upon the correctness of the concepts of modularity and adaptability. This can be evaluated as a major risk for the future of the DOCC if modularity does not turn out to be the most efficient solution, and/or if the adaptability of the DOCC is seldom or never needed in space or other markets.

Nowadays, the most important concern of space projects in meeting their mission objectives is the total mass of the spacecraft, probe, or satellite including its systems and subsystems, because of the direct relation of mass to costs (especially launch costs). Therefore, the mass budget becomes a very important issue. For the design of a modular DOCC system, problems may be

caused by the necessity to duplicate items which may be needed in the different modules. This duplication would include:

- interfaces such as connectors and cables
- functions such as malfunction prevention, and alert functions
- subsystems such as power control, computers, and thermal control

To achieve the advantage of having adaptation potential to different missions, the full integration of all subsystems has to be relinquished. This may cause a higher mass of a modular DOCC compared to a fully integrated DOCC, resulting in higher launch costs or less equipment for the same amount of payload.

Another question clinging to modularity deals with the problem of future enhancement of subsystems in the DOCC. If one modular item is enhanced in performance, data rate, or precision and is integrated in the “old” technical environment, will this be compatible or are follow-on developments predicted (which lead to additional costs)? After some years of changing the basic DOCC and adapting it to recent problems, the maturity of the subsystems will differ. Until now there has been no analysis as to whether this is acceptable or may cause problems.

11.1.1 Risk Evaluation

The risk for the modular and adaptable design approach of the DOCC is **SIGNIFICANT** and **HIGH**.

11.1.2 Actions to be Taken

- To prove the correctness of the chosen design of the DOCC, both approaches (integrated and modular) have to be compared in further studies by an additional trade-off analysis and the carrying out of two different design processes. The time limit did not allow this work to be performed in parallel in the Design Project.
- The procedures of further enhancement of the DOCC concerning interfaces and requirements have to be studied.

11.2 CORE DESIGN

If it turns out to be true that most of the medical scenarios have a common set of requirements and that there is a need for lots of DOCC's on Earth with a high potential of commercial earnings (see Section 9.3), this leads to the question of whether a core DOCC will still be a reasonable solution or in contradiction to specialised developments for each different mission which will arise. If it is assumed that there are commercial returns on investment in a future DOCC market, the risk of competing products of various companies aside from the initial manufacturer of the DOCC has to be considered. This

may lead, in time, to a changing of the idea of a core design to a set of the most suitable application-oriented specialised designs.

11.2.1 Risk Evaluation

As the question of diversification of designs will be raised after an initial design is established, the change from core design to various specific designs will be at **NO** particular risk for the future of the DOCC. This will be a normal process of enlarging markets. It is only significant for the manufacturing company to adapt as soon as possible to the market needs. Otherwise new companies will take advantage of conservative industrial product policy.

11.2.2 Actions to be Taken

- Leading DOCC manufacturer has to adapt to the market, particularly by utilising its distribution channels to incorporate market feedback into product development.
- New companies have to offer competitive products.

11.3 DOCC HARDWARE AND SERVICE FOR TERRESTRIAL USE

As mentioned in Section 9.1 the DOCC is a combination of hardware (H/W) and services.

11.3.1 Hardware

The risk associated with the hardware development depends on the set of requirements (medical and mission specific). With the experience of Russian and American manned missions in the past, and the availability of medical facilities on Earth, the development of a DOCC, in principle, can be assessed as having only **LOW** risk. Challenges for necessary technological steps are identified for miniaturisation and communications.

11.3.2 Services

The services which have to be performed by the DOCC for space applications is defined in detail by the mission and its environmental constraints. Only a few points will be added from the individual point of view from the astronauts themselves. The reason for this is because astronauts are chosen for the mission and not vice versa. The astronaut is very important for the mission but selection processes can minimise the number of further requirements.

Regarding terrestrial applications, the question of desired functions and services is completely different. If one thinks of a broad use of "Earth DOCC's" as described in Section 9.3, a great number of different patients with even more different expectations of services and interactions with the DOCC hardware will occur.

11.3.3 Risk Evaluation

Because of the lack of market research, the risk that Earth users would not accept a DOCC or expect different services for health treatment is not easy to evaluate. Human nature shows that issues of minor importance for the operational phase can have a major impact on decisions to buy, use and/or trust technical facilities or machinery. Thus, the acceptability of the DOCC by future patients is a **MEDIUM** risk. In this context the alternative of substitute hardware and service needs to be assessed.

11.3.4 Actions to be taken

- Before the DOCC can be transferred from space applications to Earth scenarios, studies and surveys of demand and acceptability have to be executed (see Section 9.2).
- Ethical questions have to be addressed in addition.

11.4 COMMERCIALISATION

The commercialisation strategy suggested in Section 9.3 for DOCC shows the existence of potential terrestrial applications. Questions will arise regarding the interrelationship between a space DOCC and related Earth "DOCC's":

Are space requirements and the developed space facilities driving follow-on equipment on Earth?

or

Will Earth-bound medical facilities be adapted to the needs in space?

Regarding the enormous market on Earth and the few missions in space, it seems to be logical that in a first step, only adaptive developments of existing Earth hardware for use in space is reasonable and economical. Even if there might be an extensive Mars scenario with dozens of flights a year, it is doubtful whether a specific medical development line for medical space facilities will arise alongside the commercial market of facilities used in hospitals and by doctors on Earth.

This leads to the next insecurity:

Will there be a return on investment for the space medical developments of a DOCC?

The answer to this question can only be given after a complete scenario of future applications is defined and the number of units which have to be produced can be estimated. The answer to this questions is very important for potential investors in the DOCC. When will they get revenues on their investment?

11.4.1 Risk Evaluation

The success of the commercial strategy depends directly on the number of DOCC units demanded in the future and the income from selling them. As long as these numbers are questioned and not manifested, the risk of the success of the commercial strategy is **HIGH**.

11.4.2 Actions to be Taken

- Future markets for the DOCC have to be researched in detail.
- Calculations of cost, customer willingness to pay, and potential income have to be performed with identification of the cost drivers and the selection of sensible parameters.

11.5 APPLICATIONS OF DOCC IN DEVELOPING COUNTRIES

Regarding the experience with advanced technology products and their use in developing countries, it has been discovered that only those products which can successfully be used over a long time period and can be produced, serviced and repaired in the country itself actually succeed. In the huge agricultural programs of the 1960's and 1970's, a lot of modern tractors were sent to 3rd world countries to support their farming activities. Most of the efforts failed because, after a while, technical defects of the machinery could not be repaired on-site due to the lack of mechanics and spare parts.

For the DOCC this means that potential customers in developing countries (mostly their governments) have to be aware of the dimension of introducing DOCC facilities for health care. Not only the operational system has to be considered but also the supporting environment, such as the education of mechanics and doctors, the provision of a reliable power supply and consideration of factors such as climatic conditions.

11.5.1 Risk Evaluation

With the broad experience of supporting developing countries through transferring high technological products in the past, this risk is assessed as **LOW** but with high significance and the danger of becoming a show stopper.

11.5.2 Actions to be Taken

- Information gathering at decision making levels of the dimension that the DOCC introduction affects.
- Analysis and support of all aspects of side problems which will arise.

11.6 MARKETING THE DOCC THROUGH AN ESTABLISHED MEDICAL COMPANY

Comparing DOCC to historical developments, a possible first marketing agent for the DOCC can be an established medical equipment company.

11.6.1 Risk Evaluation

The DOCC concept presented in this report follows innovative ideas and is competitive to existing hardware and concepts of medical care. Therefore it is doubtful whether established structures of market dominating companies can and will fully support this concept as a competitive entity. The risk that the DOCC idea may be suppressed by major players in the medical industries must on one hand be seen as **HIGH**. On the other hand it also offers a great opportunity to small or new companies to take an innovative approach to access the worldwide market of health care. With the stepped approach of Section 9.3 there are good chances to share risks with governmental bodies during the early phases.

11.6.2 Actions to be Taken

To consolidate the idea of the DOCC, feedback from the medical industry is needed. Marketing specialists have to be involved in market analysis and potential investors have to be consulted concerning future funding for this idea.

11.7 SUMMARY

In this chapter only the main risks are evaluated. The analysis is rough and has to be deepened to find the specific drivers and crucial issues. The main thought of this assessment was to examine statements and critical findings and raise points of actions to be taken in the future to pursue this project.

HIGH risks are seen in the areas of:

- The design and architecture of the DOCC as a modular and adaptable facility.
- Commercialisation of the DOCC.
- Marketing of the DOCC through an established medical Company.

Terrestrial use of the DOCC hardware and its service have been evaluated as a **MEDIUM** risk.

NO risk is seen for the development of a common core design of the DOCC.

Chapter 12

Recommendations

After looking at all aspects of current medical care in space and designing an integrated medical facility to support future manned missions, it is felt that a program of future research and development can be recommended. Much of the necessary research and development can be done on Earth; however, some can only be performed in space aboard the space shuttle or on longer duration missions aboard Mir or the future International Space Station.

12.1 CREW SELECTION

The capability to perform crew selection for the remote environment of spaceflight is crucial to the health and safety of crew members, and to the successful completion of mission objectives. Examination of medical risks indicate which areas one should concentrate on for selection, planning, resources, and training for medical care systems for further missions in particular long duration missions to Mars.

12.2 PHYSIOLOGICAL COUNTERMEASURES

Prevention of the physiological deconditioning due to hypogravity is important for the crew's health and performance capacity. The decrease in work capacity and loss of strength can be restored with intensive exercise. However, for the attenuation of the skeletal, neurosensory, immune, cardiovascular and hormonal systems there are currently no countermeasures that fully prevent and restore the hypogravity-induced changes. Furthermore, the adaptation and reactions to spaceflight in these systems are not yet fully

understood, and this makes it difficult to develop new and more effective countermeasures.

Exercise protocols with minimal time and energy consumption and maximal effect have to be determined. In addition these protocols have to be acceptable to the crew. The use of Virtual Reality (VR) during the performance of physiological countermeasures should be investigated. VR could help make regular countermeasures more enjoyable and provide an environment for relaxation.

Additional research concerning the deconditioning processes and their counteraction is necessary if safe and successful long-term missions are to be conducted.

12.3 PSYCHOLOGICAL COUNTERMEASURES

Extended duration spaceflight poses significant psychological, psychiatric, and human factor challenges for future space crews. Critical incidents relating to the psychological, behavioural, and interpersonal aspects of crew performance have, at times, jeopardised crew safety and mission success since the beginning of human spaceflight.

The ability for human crews to successfully operate in a permanently orbiting space facility and Mars base environment depends significantly on the ability to adapt crews to the stressors inherent in the spaceflight environment. The *Crew Psychological Support System (CPSS)* within the DOCC has been developed to support all aspects of crew psychological health and performance in all phases of flight through proper crew selection, training, and support with the objective of ensuring crew performance and mission success.

12.4 SURGERY

It is expected that terrestrial applications of the integrated and compact hardware and infrastructures should follow the space application design.

From the surgical requirements, one of the goals should be to build a compact laparoscopic system (television camera + light source + CO₂ inflator) that could fit in a space of about 30*20*20 cm with only the plug-ins necessary to fit the external instruments.

Other hardware devices that should be addressed are Magnetic Resonance Imaging (MRI) and lithotripsy equipment for kidney stones.

Another important progress, not only in surgery but in all medical fields, is to create standards to facilitate communication among people from different countries and with different backgrounds, such as medical records, medical language, data transfer protocols and medical procedures.

12.5 PHARMACEUTICALS

In order to determine the amount and types of drugs for a pharmaceutical kit, a study on the drug absorption and elimination in the human body in microgravity is necessary. Also, research and development of pharmaceuticals that allow oral administration (instead of intravenous or intramuscular) and that are not affected by the altered physiology, is needed.

The pharmaceutical and dental kit for space applications should be designed and supplied for at least one year in order to avoid unnecessary resupply.

12.6 TELEMEDICINE

Microgravity simulation experiments and trials have shown the potential of telemedicine to improve health care delivery in the space environment, yet the expense of the technology has precluded widespread adoption in Earth applications. Now, with emerging technologies, lowered costs, and the development of information superhighways, telemedicine may finally reach its potential, providing opportunities for both cost reduction and improved patient outcomes for Earth and space applications. Barriers to implementation remain, however, and human factors such as resistance to change are the greatest barrier to full scale deployment of telemedicine services.

12.7 SPACE MEDICINE RESIDENCY TRAINING PROGRAM

The space medicine residence training which will be established in the future to prepare medical doctors to serve as space physicians, will be a broad training in a multidisciplinary program. The residency will take five years to complete. Upon completion, the physician will be trained as both a medical doctor and an astronaut, ready for long duration space missions.

12.8 COMPUTERISED HEALTH MAINTENANCE SYSTEM

One of the potential technology transfers of the design project is the creation and implementation of the Computerised Health Maintenance System (CHMS) for rural and geographically isolated communities, in order to help doctors administer advanced treatments and provide accurate diagnoses. During the construction of the CHMS the software may be tested in isolated environments. Once the product is functioning at an acceptable level it will be used as a treatment and diagnostic tool.

Medical knowledge is expanding at a remarkable pace. Technology such as the CHMS may be one of the best methods for physicians to keep abreast of new treatments and diagnoses. In the future, methods should also be developed to quickly integrate new information into information frameworks. Several liability and legal problems must also be worked out before products as the CHMS can be used extensively in terrestrial environments.

In addition, developing and utilising the CHMS will require legal agreements regarding medical liability to be developed. Once clear legal guidelines are established, this will increase the utilisation of medical computer tools such as the CHMS.

Physicians should not be wary that systems such as the CHMS will replace them. Computerised systems will always be tools, and will only allow physicians to provide better care to their patients.

12.9 INCREASED CREW AUTONOMY

Increased crew autonomy is desirable because it can reduce the ground segment cost of manned spaceflight operations. It will also lead to a more productive crew, able to achieve more in a given time. There will be an increased risk associated with autonomy, however, and a programme should be developed to increase experience in crew autonomy. There should also be development of on board systems to aid the crew in decision making and to provide necessary information as required. In the case of a Mars mission, increased crew autonomy is essential due to the time delay in communications. It will be desirable to use commercial off-the-shelf systems, although there may be problems associated with safety requirements and the effects of radiation on the electronics.

12.10 IN-FLIGHT TRAINING

As longer time is spent in space there is a need for in-flight training for flight procedures and equipment operations. This will be especially important for medical contingency procedures and the maintenance of medical equipment which, by their nature, will occur infrequently, but will require quick action when they do. There are interesting technologies available now which could be used for such a system, from simple video links to ground, through traditional manuals and computer based training. In the short term, the developments in virtual reality and improved reality technologies will undoubtedly have applications in this area and should be explored further.

12.11 AUTOMATED INVENTORY TRACKING

In order to minimise the time that is spent by humans in space on non-mission related functions, it is recommended that an automated inventory tracking system be incorporated into the DOCC facility. One way of doing this would be to develop current bar code scanning technologies for use in space. All inventoried materials in the DOCC would be labelled with a bar code, which would be "swiped" through the scanner before use. This information would then be sent automatically from space to the ground control centre, who would be responsible for resupply activities.

12.12 DATA HANDLING AND COMMUNICATIONS

Efficient communications and computer-based systems are paramount in order to maximise the performance of any space mission or specific module designed today. The DOCC facility is not an exception.

In designing the communication system of the DOCC, advantage should be taken from already existing techniques in space missions. Also, in the data handling process, simplifications can be made by utilising systems with similar requirements from other science fields such as remote sensing. This knowledge simplifies the design of the communication and data handling systems to be used and allows concentration on off-the-shelf solutions driven by cost reduction factors.

The analysis of the bandwidth required for the different medical applications indicates that this resource will not limit dramatically the performance of the DOCC. Video application could suffer the bandwidth limitation on far away locations such as Mars. In this case, the basic physical communication delay existing at such distance is a more significant limitation.

State-of-the-art compression techniques, data security and encryption issues have been studied in the research of this report, and it is impossible to say which particular technique will be used in a particular mission. The rate at which computer science evolves is such that every year new algorithms and techniques appear. What it is important to know is that the techniques existing today could already be used in DOCC applications. In the future it is expected that further improvements will result in the optimisation of the DOCC performance.

A clear example of the similar systems existing in other science fields is the GIS (Geographical Information Systems). The generalisation of this concept for medical applications could bring about the MIS (Medical Information System) concept. The integration of medical data in computer based systems formed by databases and data storage devices will help the medical community to take full advantage of the data acquired by the different means.

12.13 POLICY AND LAW

Political challenges have always had and will continue to have an impact on the development of space activities at both national and international levels. It is important to examine the rationale underlying a State's acceptance and funding of major technological undertakings, particularly when they relate to outer space, as this is a sector which poses some very distinctive challenges.

It is not difficult to envision the intrinsic value and the various applications of a medical facility such as DOCC. National health care institutions will surely benefit both in the provision of medical care and in the education of their medical practitioners. Moreover, the future of long-term space missions will naturally be dependent on the guarantee of crew safety and health.

For a State to commit to and spend money on large-scale space endeavours, it must have justifiable reasons. There are several reasons why a State will be willing to fund (justify the investment to its citizens) the DOCC: international and national prestige, potential terrestrial applications, technological development, possible privatisation or commercialisation and most importantly, *providing an Earth-like medical infrastructure to encourage future manned space missions.*

12.14 SYSTEM ARCHITECTURE

If a medical system which is capable of supporting the wide range of missions planned for the future of space exploration and development is to be built, it will have to be based on a core module which integrates the best current knowledge of medical treatments required in space and the best technology available for those treatments.

It is recommended that future research focus on the development of a comprehensive medical database for space, the improvement of medical technology and, especially, on the development of innovative structures which will allow designers and architects to design comfortable environments without prohibitive mass or financial cost.

It is also suggested that the use of virtual reality be investigated for private communication between crew members and their friends and relatives on the ground, and also to help create a private personal space instead of creating individual crew compartments inside a space station or a Mars mission. Both of these psychological aspects of virtual reality in long duration spaceflight require more study.

12.15 RISK ASSESSMENT

A rough analysis and risk assessment shows that some aspects of the DOCC have high risks for the future of the project. The main questions are whether

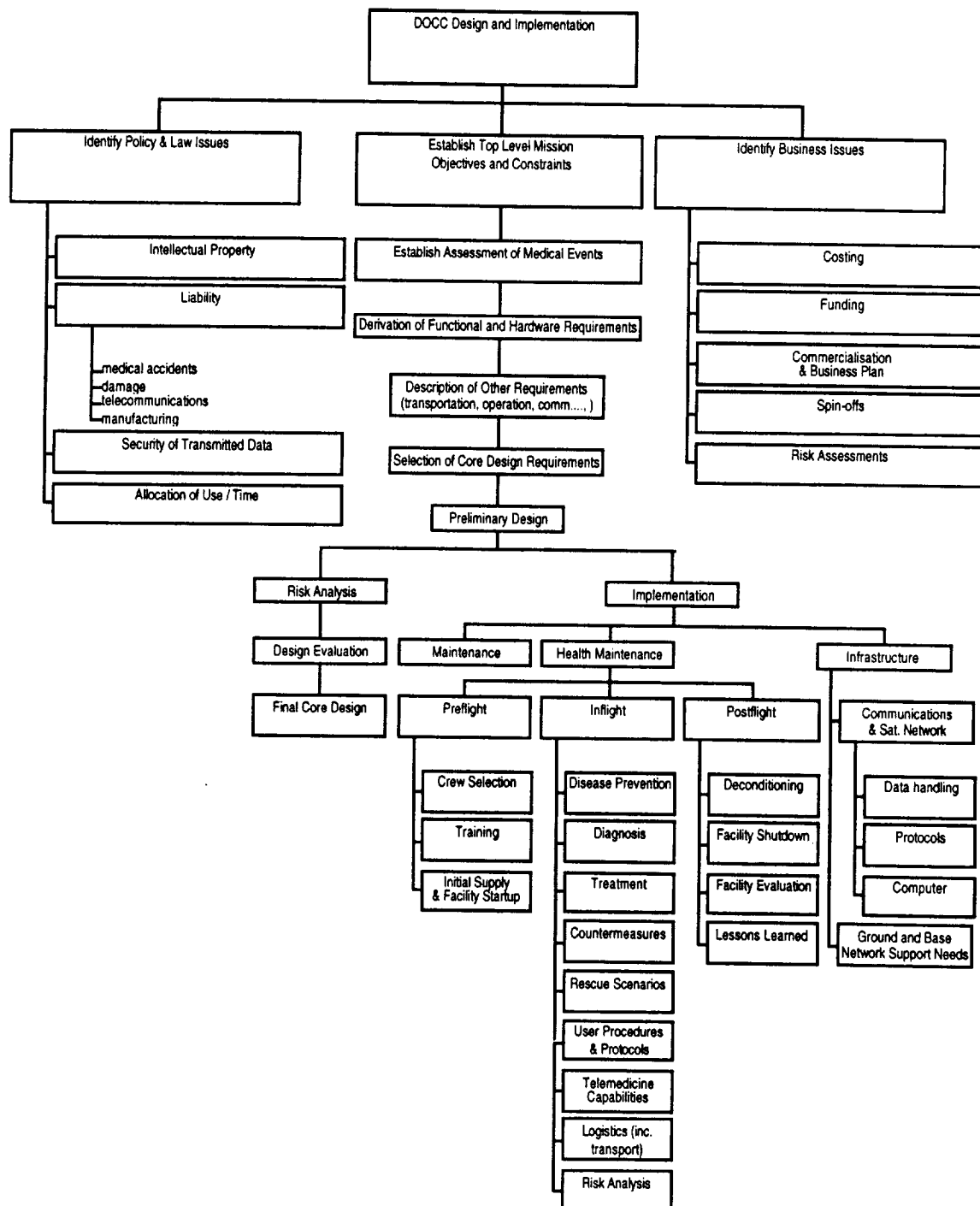
- the design and architecture of the DOCC as a modular and adaptable facility is the right approach.
- commercialisation of the DOCC is possible.
- marketing of the DOCC through an established medical company will be the best way to sell the DOCC around the world.

Because of the time constraints of the Design Project further analyses have to be performed to identify critical parameters, design drivers and possible show stoppers of the DOCC. In this context, it has to be emphasised again that the DOCC project offers an enormous potential for future medical care enhancements, both in space and on Earth.

Appendices

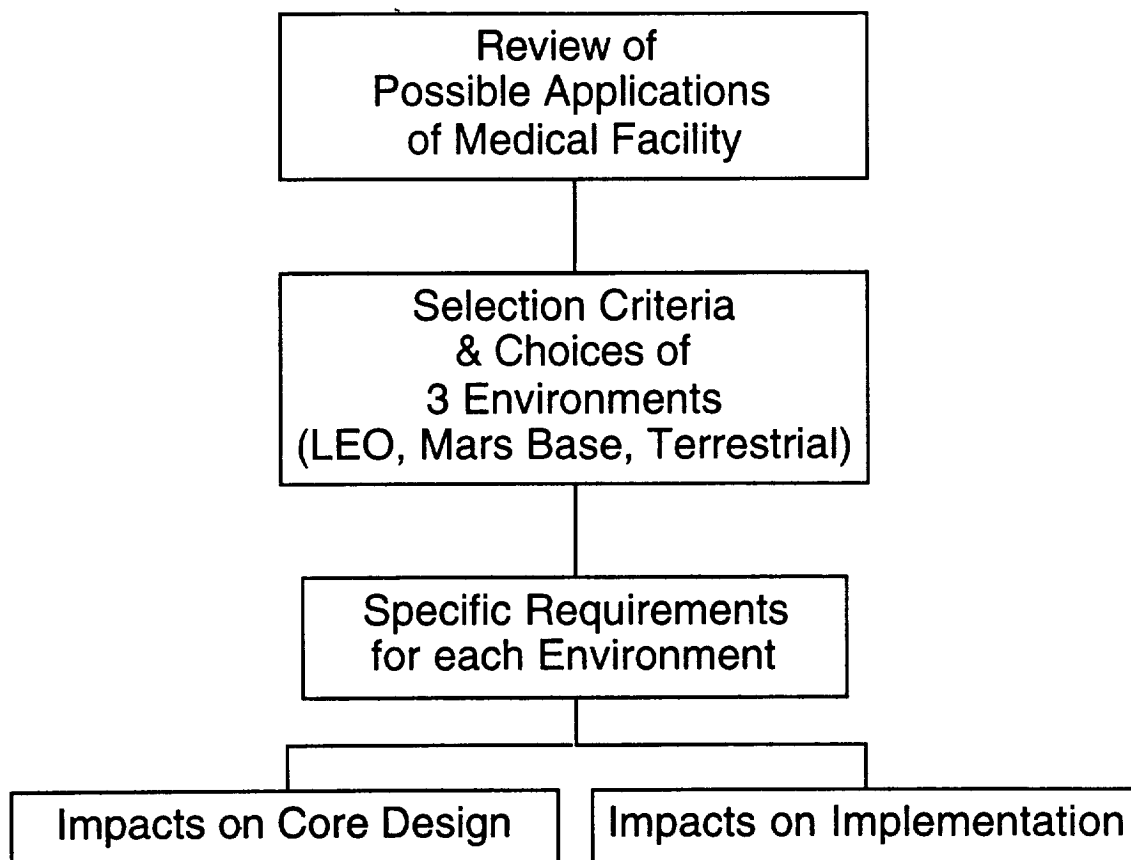
Appendix A

WORK BREAKDOWN STRUCTURE



Appendix B

PROJECT STRUCTURE FOR DIFFERENT ENVIRONMENTS



Appendix C

EVENT	MEDICAL PROBLEM	COUNTER-MEASURE	MONITORING / DIAGNOSTIC EQUIPMENT	TREATMENT	HARDWARE (see Table 1.12 for further Hardware details)	GROUND ELEMENT
			All these can predict the presence or imminent presence of kidney stones.)			
	5. Decreased Immunity	- Environmental Control & Life Support System (ECLSS) to control overgrowth of micro-organisms (see EVENT: ECLSS: Failure of Microbiology Control System: Countermeasures) - Hydration (drink more fluids) - Repletion of depleted electrolytes (Example: Food supplemented with potassium)	- Clinical Chemistry Analysers (specifically, Complete Blood Count to measure any change in the numbers, shape, and cellular characteristics of circulating blood cells) - Clinical Chemistry Analysers	- Pharmaceuticals - Antibiotics	- Clinical Chemistry Analysers - Antibiotics	Video and Data Monitoring by ground based internist
	6. Fluid & Electrolyte Imbalance (electrolytes are those ions in the blood and body fluids such as sodium, potassium, chloride, calcium, and phosphate) (An imbalance can lead to altered heart rhythm, altered nerve transmission, and potentially death.)	- Hydration (drink more fluids) - Repletion of depleted electrolytes (Example: Food supplemented with potassium)	Clinical Chemistry Analysers	Repletion of depleted electrolytes	Clinical Chemistry Analysers	Video and Data Monitoring by ground based internist
	7. Neurovestibular Deconditioning (NVD) (decreased reliance on vestibular apparatus [inner ear balance organ] and increased reliance on visual cues) (NVD becomes a problem upon return to gravity environment.)	Pre-flight Sensory Conflict Simulations	Neurocognitive Assessment	- Standard Diagnostic Tools - Psychological support of CM	Standard Diagnostic Tools	Video and Data Monitoring by ground based neuro-vestibular expert
	8. Space Motion Sickness (SMS) (nausea, vomiting, headache) (Onset is 3-5 hours post-launch and Duration is approx 2 days)	Pre-flight Sensory Conflict Simulations	Physical examination	- Pharmaceuticals: - anti-nausea - relief of headache - Fluid and electrolyte repletion	Pharmaceuticals	Video and Data Monitoring by ground based internist and neuro-vestibular expert
	9. Vitamin D deficiency (exposure of the skin to direct sunlight is required for Vitamin D production in the skin)	Supplements of the essential vitamins and minerals	Periodic Physical Examination	Increase dietary intake of vitamin D (and other vitamins in a multi-vitamin pill)	Pharmaceuticals	Video and Data Monitoring by ground based internist
	10. Musculoskeletal Injuries - Back strain - Knee / ankle / wrist strain (especially in EVA) - Fractures: - crush fracture of fingers - stress fracture of leg bones (when ambulating on Mars surface)	- Aerobic and Resistive Exercise to increase strength of joints, ligament, tendons, and muscles, and bones - Careful attention to posture, spacesuit design, and foot restraint design for EVA	- Physical Examination - X-ray Device	- Casts or Splints - Pharmaceuticals - pain relief - reduce inflammation	- Treadmill - Cycle Ergometer - Multi-Axial Resistive Exerciser - Pharmaceuticals and Medical Supplies - X-ray Device	Video and Data Monitoring by ground based internist, orthopedic surgeon (bone repair surgeon), and physiotherapist
2. Loss of Pressure within spacesuit during EVA	1. Decompression Disorders, consisting of: Bends (classically termed Decompression Sickness (DCS) (nitrogen dissolved in the blood comes out of solution to form nitrogen bubbles in the tissues, particularly the joints))	Pre-breathe oxygen with Portable Breathing Apparatus (example: A slow leak within the cabin of 1 PSI per 30 minutes would necessitate pre-breathing with oxygen [as well as fixing the source of the problem].) (Pre-breathing with oxygen displaces nitrogen gas dissolved in the blood, thereby reducing the	- Physical exam using Standard Diagnostic Tools - Ultrasound (to visualize and estimate the volume of air bubbles within the blood) - Standard Diagnostic Tools - Oximeter (to measure blood oxygen saturation)	- Portable Breathing Apparatus - Hyperbaric capability (increase the pressure within SC so that nitrogen gas that was evolved in depressurization becomes redissolved). - Supportive medical care as needed:	- Portable Breathing Apparatus - Ultrasound - Standard Diagnostic Tools - Oximeter - ICU Equipment	Video and Data Monitoring by ground based internist dermatologist (skin specialist) (because there are characteristic skin rashes associated with

	CONTAINER MEASURE	MONITORING / DIAGNOSTIC EQUIPMENT	TREATMENT	HARDWARE (see Table I.12 for further Hardware details)	GROUND ELEMENT
	• Aerocombolism (air bubbles in the blood vessels due to rupture of pulmonary tissue.) (This is a serious form of Barotrauma - see below.) • Ebullism (exposure of body to pressure less than 47 mm Hg which is the vapour pressure of water at 37°C. In effect, the boiling away of body fluid.) 2. Hypoxia (decreased oxygen levels in the blood) 3. Barotrauma • ear block • sinus block		• IV fluids • Pharmaceuticals • ICU Monitoring if required		Decompression Sickness)
3. Toxic Substance Release (solids, liquids, gases); • propellants (e.g. hydrazine) • coolants • Payload chemicals (such as lubricants and tissue fixatives)	1. Pulmonary Edema (a serious condition in which the air sacs in the lungs fill with fluid and can no longer exchange oxygen with the blood.)	• Volatile Organic Analyser • Compound Specific Analyser - Hydrazine • Compound Specific Analyser - Combustion Products • Portable Breathing Apparatus • Contamination Protection Equipment (that might be worn when fixing the source of the contamination): • gloves • goggles • eye wash	• Portable Breathing Apparatus • ICU Equipment • ICU Monitoring if required (if CM condition is serious) • Pharmaceuticals • bronchodilators (increase the size diameter of the lung airways thereby increasing air flow volumes) • antidotes	• Volatile Organic Analyser • Compound Specific Analyser - Hydrazine • Compound Specific Analyser - Combustion Products • Portable Breathing Apparatus • Contamination Protection Equipment: • gloves • goggles • eyewash • ICU Equipment • Clinical Chemistry Analysers • Urine Chemistry Analyser • Pharmaceuticals	• Video and Data Monitoring by ground based internist
2. Eye irritation	• As above	• Eye exam	• Supportive measures	• Ophthalmoscope • Slit lamp • Pharmaceuticals	• Video and Data Monitoring by ground based ophthalmologist (eye specialist)
3. Mucous Membrane irritation (irritation of the nose, mouth, throat, and airways of the lungs)	• As above	• Physical Examination	• Pharmaceuticals	• Standard Diagnostic Tools • Pharmaceuticals	• Video and Data Monitoring by ground based internist
4. Skin irritation: 5. contact dermatitis 6. chemical burns	• As above	• Physical Examination	• Pharmaceuticals • Bandages	• Pharmaceuticals • Bandages	• Video and Data Monitoring by ground based internist and dermatologist (skin specialist)

EVENT	MEDICAL PROBLEM	COUNTER-MEASURE	MONITORING / DIAGNOSTIC EQUIPMENT	TREATMENT	HARDWARE (see Table 1.12 for further Hardware details)	GROUND ELEMENT
	7. CNS disturbances	• As above	- Physical Examination - Standard Diagnostic Tools	Pharmaceuticals	Pharmaceuticals	Video and Data Monitoring by ground based internist and neurologist
	8. Cardiac arrhythmia (abnormal electrical conduction in the heart) (example: cardiac arrhythmia may result from Halon 1301 used to extinguish fires)	• As above	- Physical Examination - Standard Diagnostic Tools - ECG Monitor	- ECG Monitor - Intensive Care Monitoring if required	- Pharmaceuticals - Physical Examination - Standard Diagnostic Tools - ECG Monitor - Intensive Care Equipment if required	Video and Data Monitoring by ground based internist
4. Fire	- Burns - Smoke Inhalation - Hypoxia (decreased oxygen levels in the blood)	- Detectors - Portable Breathing Apparatus	- Standard Diagnostic Tools - Clinical Chemistry Analysers (specifically a Complete Blood Count to measure any change in the numbers, shape, and cellular characteristics of circulating blood cells) - Urinalysis - Central Nervous System (CNS) Evaluation - Oximetry (measure of the oxygen content of the blood) - Metabolic Gas Analyser (measure of the volumes of inspired gas [oxygen] and expired gas [carbon dioxide] in the lungs)	- ICU Monitoring if required - Bandages - IV fluids	- ICU Equipment - Bandages - IV fluids - Clinical Chemistry Analysers - Clinical Chemistry Analyser - Oximeter	Video and Data Monitoring by ground based internist
5. Impact (upon landing on Earth / Lunar / Mars surface)	- Trauma - lacerations - fractures	- Primary Impact Attenuation System - Physical conditioning	- Accelerometers - Imaging - ICU Monitoring if required - Surgery	- ICU Equipment - Surgical Equipment	- ICU Equipment - Surgical Equipment	Video and Data Monitoring by ground based internist, surgeon, orthopedic surgeon (bone repair surgeon), and physiotherapist
6. Environmental Control & Life Support System (ECLSS) Failure	- Failure of Carbon Dioxide Removal System: Hypercapnia (elevated carbon dioxide level in the blood, leading to confusion and if continued unconsciousness and death) - Failure of Air Revitalization / Air Supply System: Hypoxia (decreased oxygen levels in the blood, leading to	Portable Breathing Apparatus	- ECLSS Monitoring - Capnograph (measures level of carbon dioxide in the blood)	Portable Breathing Apparatus	- Portable Breathing Apparatus - Capnograph	Video and Data Monitoring by ground based internist
		Portable Breathing Apparatus	Oximeter	Portable Breathing Apparatus	- Portable Breathing Apparatus - Oximeter	Video and Data Monitoring by ground based internist

	COUNTER-MEASURE	MONITORING / DIAGNOSTIC EQUIPMENT	TREATMENT	HARDWARE (see Table 1.12 for further Hardware details)	GROUND ELEMENT
	confusion and if continued then unconsciousness and death)				
	Failure of Pressure Control System: • see EVENT: Loss of Pressure				
	Failure of Microbiology Control System (leading to overgrowth of bacteria and fungi on SC interior surfaces and water supply): • <u>Respiratory infections</u> • <u>Skin infections</u> • <u>Eye infections</u> • <u>Gastroenteritis</u> (feeling of "upset stomach", nausea, vomiting, diarrhea [causing depletion of fluids and electrolytes])	• Microbial Air Sampler • Surface Sampler Kit • Fungal Microbiology Kit • Fungal Spore Sampler • Incubator • Microbiology Safety Cabinet • Microscope & Camera • Slide Staining Apparatus • Water Sampler & Archiver • Spectrophotometer • Total Organic Carbon Analyser • Ion Selective Electrode Assembly	• Periodic Physical Examination • Analysis of microbial type and population density from samples of SC interior surfaces, water supply, cabin air, and CM skin, blood, Ventilatory secretions, urine and feces.	• Microbial Air Sampler • Surface Sampler Kit • Water Microbiology Kit • Fungal Spore Sampler • Incubator • Microbiology Safety Cabinet • Microscope & Camera • Slide Staining Apparatus • Pharmaceuticals • Water Sampler & Archiver • Spectrophotometer • Total Organic Carbon Analyser • Ion Selective Electrode Assembly	• Video and Data Monitoring by ground based internist and microbiologist (specialist in infectious disease)
	Failure of Particulate Matter Removal System I: • Foreign body in the eyes	• Eye exam • Ophthalmoscope • Slit lamp	• Ophthalmic kit for removal of foreign body	• Goggles • Personal Air Filters worn by CMs	• Video and Data Monitoring by ground based ophthalmologist.
	Failure of Particulate Matter Removal System II: • Foreign body in the lungs	• Respiratory infection • Impaired breathing	• ICU Monitoring if required • Endoscope • Pharmaceuticals	• ICU Equipment • Endoscope • Pharmaceuticals	• Video and Data Monitoring by ground based internist
	Failure of Trace Contaminant Removal System: see EVENT: Toxic Substance Release				
	Failure of Thermal Control System I: • Hyperthermia	• Fluid and electrolytes monitoring • Temperature Monitoring	• Increase fluid and electrolyte intake	• Personal Temperature Monitor	• Video and Data Monitoring by ground based internist
	Failure of Thermal Control System II: • Hypothermia	• Temperature Monitoring		• Personal Temperature Monitor	• Video and Data Monitoring by ground based internist
7. Noise / Vibrations	• Sleeplessness • Decreased acuity of hearing • Psychiatric problems (example: Noise may contribute to Adjustment Disorder)	• Audiometer (to test acuity of hearing) • Noise dosimeters	• Noise attenuation • Hearing Protectors	• Noise dosimeters • Audiometer • Hearing Protectors	• Video and Data Monitoring by ground based internist and psychiatrist

EVENT	MEDICAL PROBLEM	COUNTER-MEASURE	MONITORING / DIAGNOSTIC EQUIPMENT	TREATMENT	HARDWARE (see Table 1.12 for further Hardware details)	GROUND ELEMENT
8. Radiation	- Chronic low level radiation: - increased cancer risk - Acute radiation exposure: - Minor: nausea, vomiting, lethargy - Major: Decline / cessation of bone marrow production of red cells (leading to anemia and weakness) and white cells (leading to multiple infections), death	- Chronic radiation exposure: - Shielding of SC - Acute radiation exposure: If imminent radiation hazard is detected, then: - safe haven - prophylactic Pharmaceuticals - Dosimeters: - Crew Passive Dosimeters - Radiation Area Monitors - High Rate Dosimeters - Intra-Vehicular Charged Particle Directional Spectrophotometer - Extra-Vehicular Charged Particle Directional Spectrophotometer - Tissue Equivalent Proportional Counter	- Dosimeters: - Crew Passive Dosimeters - Radiation Area Monitors - High Rate Dosimeters - Intra-Vehicular Charged Particle Directional Spectrophotometer - Extra-Vehicular Charged Particle Directional Spectrophotometer - Tissue Equivalent Proportional Counter - Clinical Chemistry Analysers	- Pharmaceuticals - Intensive Care Unit equipment - IV fluids - GM-CSF (Granulocyte Monocyte - Colony Stimulating Factor) (organic compound which stimulates white cells of the immune system to proliferate) - Bone Marrow Transplant ?	- Dosimeters: - Crew Passive Dosimeters - Radiation Area Monitors - High Rate Dosimeters - Intra-Vehicular Charged Particle Directional Spectrophotometer - Extra-Vehicular Charged Particle Directional Spectrophotometer - Tissue Equivalent Proportional Counter - Clinical Chemistry Analysers	Video (of blood smear microscope images) for analysis by ground based pathologist
9. Dust Contaminant ion (especially on Lunar / Mars surface)	Foreign body in the eyes	Eye protection: goggles	- Dust Analysis - Slit lamp (special instrument to inspect the surface, interior, and retina of the eye)	- Eye wash - Ophthalmologic kit for removal of foreign body from the eye	- Eye goggles - Eye wash - Ophthalmologic kit - Slit lamp - Pharmaceuticals	Video and Data Monitoring by ground based ophthalmologist
	Airway / lung irritation	- Air filters in the SC - Personal Air Filters worn by CMs to filter inhaled air	- Physical Examination - Metabolic Gas Analyser (measure of the volumes of inspired gas [oxygen] and expired gas [carbon dioxide] in the lungs) - Endoscopy (broncho-alveolar lavage to examine lung tissue) - Chest X-ray - Inspection of skin	- Pharmaceuticals (broncho-dilator drugs to enlarge the diameter of the airways and thus increase air flow volumes in the lungs) - Ventilator	- Personal Air Filters - Pharmaceuticals - Metabolic Gas Analyser - Endoscope - X-ray device	Video and Data Monitoring by ground based internist
	Skin irritation	Clothing requirements	Inspection of skin	- Pharmaceuticals - Medical supplies (such as light bandage to cover irritated skin)	- Pharmaceuticals - Medical supplies	Video images for analysis by ground based dermatologist
10. Nutritional / Metabolic	Vitamin D deficiency (exposure of the skin to direct sunlight is required for Vitamin D production in the skin)	Supplements of the essential vitamins and minerals	Periodic Physical Examination	Increase dietary intake of vitamin	Pharmaceuticals	Video and Data Monitoring by ground based internist
II. PRIMARY MEDICAL EVENT						
(= medical problems that occur not directly due to spaceflight)						
I. Vascular	Atherosclerosis (deposition of fat	Selection criteria for CMs	ECG Monitoring	Proper Diet	Standard	Video, Audio,

		COUNTER-MEASURE	MONITORING / DIAGNOSTIC EQUIPMENT	TREATMENT	HARDWARE (see Table 1.12 for further Hardware details)	GROUND ELEMENT
(concerning the heart and circulatory system):	and cholesterol in the wall of an artery causing a reduction in the diameter of the artery) which potentially results in:	- Control Risk Factors for atherosclerosis: - smoking - diet high in saturated fats - lack of exercise - Aerobic Exercise. - treadmill - cycle ergometer - Periodic Stress Test (defined in next column) - Periodic Physical Examination - Periodic Blood Chemistry Analysis	(measurement of the quality of electrical conduction in the heart and the integrity of the heart muscle) - Periodic Stress Test (an ECG measurement of the heart's ability to increase its output during a defined exercise regime on the treadmill or cycle ergometer) - Periodic Physical Examination using Standard Diagnostic Tools	- Aerobic Exercise - Chest X-ray - If Vascular Event occurs then require ICU Equipment and Monitoring: - Defibrillator (if applicable) - ECG - Ventilator - Oximetry - Pharmaceuticals - Maintain fluids and electrolytes	Diagnostic Tools - ECG - Treadmill - Cycle ergometer - Standard - Diagnostic Tools - Clinical Chemistry Analysers - X-ray device - ICU Equipment: - Defibrillator (if applicable) - ECG - Ventilator - Oximetry - Pharmaceuticals - Maintain fluids and electrolytes	and Data Monitoring for ground based cardiologist.
- Atherosclerosis - Arrhythmia - Strokes	- Ischemia (lack of flow of blood to the heart because artery diameter is diminished) - Angina (pain felt in the chest due to ischemia of heart muscle cells) - Myocardial Infarct (ischemia to the point where heart muscle cells are so deprived of oxygenated blood that they die. This is a "heart attack".) - Congestive Heart Failure (the pumping action of the heart begins to fail, with the result that pressure within the blood vessels increases and forces some of the fluid portion of the blood into the lung's air spaces thereby reducing air exchange) - Arrhythmia (abnormal electrical conduction in the heart) which may be associated with EVA activity and LBNP (Lower Body Negative Pressure countermeasures for cardiovascular conditioning - see EVENT:Microgravity) - Cerebrovascular Accident (CVA) ("Stroke") (permanent or transient loss of blood flow to the brain with permanent or temporary neurological deficits)	- Microbial Air Sampler - Surface Sampler Kit - Water Microbiology Kit - Fungal Spore Sampler - Incubator - Microbiology Safety Cabinet - Microscope & Camera - Slide Staining Apparatus - Decontamination of SC internal surfaces and water supply	- Periodic Physical Examination - Analysis of microbial type and population density from samples of SC interior surfaces, water supply, cabin air, and CM skin, blood, Ventilatory secretions, urine, and feces.	- Pharmaceuticals - Supportive measures (such as IV fluids in the case of the diarrhea associated with gastroenteritis)	- Microbial Air Sampler - Surface Sampler Kit - Water Microbiology Kit - Fungal Spore Sampler - Incubator - Microbiology Safety Cabinet - Microscope & Camera - Slide Staining Apparatus - Pharmaceuticals	Video and Data Monitoring by ground based internist, dermatologist, and pathologist.
2 Infectious Disease	- Respiratory infections - Skin infections - Eye infections - Gastroenteritis (feeling of "upset stomach", nausea, vomiting, diarrhea (causing depletion of fluids and electrolytes)) - Urinary tract infections (typically these are bacterial infections of the urinary bladder)					

EVENT	MEDICAL PROBLEM	COUNTER-MEASURE	MONITORING / DIAGNOSTIC EQUIPMENT	TREATMENT	HARDWARE (see Table 1.12 for further Hardware details)	GROUND ELEMENT
3. Dental	• Caries (tooth cavity requiring a filling / extraction) • Fractured tooth • Laceration of soft tissue • Cracked tooth or cusp • Pulpitis (inflammation of the pulp cavity containing nerves and blood vessels of an individual tooth) • Periapical abscess (infection around the tooth)	• Oral hygiene (regular brushing and flossing) • Diet • Fluoride supplements • X-ray of teeth	• Periodic dental examination • Dental handheld instruments • Dental ancillary supplies • Restorative materials (for fillings) • Pharmaceuticals • X-ray device	• Standard dental procedures	• Dental handheld instruments • Dental ancillary supplies • Pharmaceuticals • Restorative materials (for fillings) • X-ray device • Sterilization equipment	• Video and Data Monitoring by ground based dentist
4. Surgical	• Wound • Surgical Abdomen (appendicitis, cholelithiasis [gall bladder stones], certain gynecologic conditions)	• Adherence to Safety Rules • Removal of appendix before long duration mission ?	• Periodic Physical Examination • Standard Diagnostic Tools	• Standard surgical procedures • Stored blood products if transfusion necessary • Fresh Frozen Plasma (Plasma is blood minus red cells and white cells.) • Packed Red Blood Cells ("shelf life" = 180 days, therefore Autologous Transfusion [CM donates their own blood every 180 days ?]) • Pharmaceuticals	• Standard Diagnostic Tools • Surgical instruments • Endoscopy instruments • Ultra-Sound device • ECG • Ventilator • Anaesthesia apparatus • Pharmaceuticals • Supplies: gauze, bandages • Freezer (for storing blood products)	• Video and Data Monitoring by ground based internist and surgeon
5. Skin	• Contact Dermatitis	• Air filters • Control of inciting agents (solvents, chemical reagents)	• Periodic Physical Examination	• Pharmaceuticals • Removal of offending agent	• Pharmaceuticals • Bandages to protect irritated skin	• High Resolution Video for ground based dermatologist.
6. Gastrointestinal	• Gastroenteritis (feeling of "upset stomach", nausea, vomiting, diarrhea [causing depletion of fluids and electrolytes]) • Peptic Ulcer Disease (PUD) (the lining of the stomach is eroded by stomach acid) • Erosions (less intensive erosion than an ulcer)	• Maintain integrity of food and water supplies (see EVENT:EECLS) • Medical Prophylaxis (Prior to departing Earth, CMs take antibiotics for the bacteria <i>Helicobacter pylori</i> which is strongly implicated as a cause PUD.)	• Periodic Physical Examination • Standard Diagnostic Tools	• Pharmaceuticals • Repletion of fluids and electrolytes	• Standard Diagnostic Tools • Endoscopy • Clinical Chemistry Analysers	• Video and Data Monitoring by ground based internist
	• Others: • Cholecystitis (infection of the gall bladder)	• as above	• as above	• as above	• as above	• Video and Data Monitoring by ground based internist

SYSTEM	PROBLEM/CONDITION	COUNTER-MEASURE	MONITORING / DIAGNOSTIC EQUIPMENT	TREATMENT	HARDWARE (see Table 1.12 for further Hardware details)	GROUND ELEMENT
		- Irritable Bowel Syndrome - Pancreatitis				
7. Gynecological	Menorrhagia (excessive menstrual flow in females)	Iron supplements (but beware iron overloading because total red cell mass is decreased in microgravity and excess iron causes hemochromatosis which is deposition of iron in the liver and other organs, leading to dysfunction)	- Periodic Physical Examination - Standard Diagnostic Tools - Clinical Chemistry Analysers	- Pharmaceuticals - Iron supplementation - Fluid and electrolyte repletion	- Pharmaceuticals - Standard Diagnostic Tools	Video and Data Monitoring by ground based gynecologist (specialist in the female reproductive tract)
8. Genito-Urinary	- Prostatitis (infection of the prostate gland) - Cystitis (infection of the urinary bladder) - Pyelonephritis (infection of the kidney)	- Attention to personal hygiene - Meet or exceed fluid intake requirements	- Periodic Physical Examination - Standard Diagnostic Tools - Clinical Chemistry Analysers	- Pharmaceuticals: - anti-inflammatory - anti-biotics - pain relief - Attention to personal hygiene - Meet or exceed fluid intake requirements	- Periodic Physical Examination - Standard Diagnostic Tools - Clinical Chemistry Analysers - Pharmaceuticals	Video and Data Monitoring by ground based internist
9. Ophthalmic	- Acute Glaucoma (an increase in pressure inside the eyeball which compresses blood supply to the optic nerve, potentially causing blindness if untreated) - Initis - Complicated Fungal and Bacterial Infections leading to Corneal Ulceration	Tonometer (pen-sized instrument in Ophthalmic Kit used for detecting glaucoma)	- Periodic eye examination - Slit Lamp	Pharmaceuticals	- Ophthalmic Kit - Pharmaceuticals - Slit Lamp	Video and Data Monitoring by ground based ophthalmologist
10. Psychiatric	- Major Affective Disorders such as: - Major Depression - Bipolar Disorder (Manic Depression) - Psychotic Disorder such as: - Schizophrenia - Secondary Reaction: - Adjustment Disorder due to: - Isolation - Stress	- Pre-screening of CMs for personal and family history of psychiatric disorders - Psychological Countermeasures to counteract Isolation and Stress: - Family Conferences - Letters (electronic) - News and Information - Recreation	Periodic Neurocognitive Assessment	- Pharmaceuticals - Pharmaceuticals - Alleviation of factors causing mental strife	- Pharmaceuticals - Pharmaceuticals	- Video and Audio Monitoring of CM speech, activities, and interactions for ground based psychiatrist - Video and Audio Monitoring of CM speech, activities, and interactions for ground based psychiatrist

- Abbreviations used in this table:

CM - Crewmember; ECG - Electrocardiograph; ECLSS - Environmental Control & Life Support System
ICU - Intensive Care Unit; IV - Intravenous; SC - Spacecraft

Appendix D

FUNCTIONAL DOCC HARDWARE LIST

Medical Computer System

1. Laptop Computer
2. Video Monitors
3. Software

Portable First Aid

1. Airway Management System
2. Pharmaceuticals & Supplies
3. Standard Diagnostic Tools
4. Defibrillator
5. Crew Medical Restraint System

Standard Diagnostic Tools

1. Blood Pressure Measurement Device (Sphygmomanometer)
2. Ophthalmoscope
3. Otoscope
4. Digital Stethoscope

Intensive Care Unit Equipment

1. Blood Pressure Measurement Device
2. Defibrillator
3. Electrocardiograph (ECG)
4. Electroencephalograph (EEG)
5. Intravenous Pump
6. Metabolic Gas Analyser (MGA)

7. Oximeter
8. Temperature Probe
9. Ultra-sound Device (2-Dimensional Echograph)
10. Ventilator
11. X-ray Device

Pharmaceuticals & Supplies

1. Pharmaceuticals
2. Intravenous (IV) Fluids
3. Bandages, Gauze, Sterile Drapes
4. Plaster, Splints
5. Blood Supply
6. Refrigerator
7. Freezer

Surgical Equipment

1. Anaesthesia Apparatus
2. Endoscopic Surgical Kit
3. Surgical Glove Box
4. Intensive Care Unit Equipment
5. Refrigerator
6. Sharp Trash Container
7. Soft Trash Container
8. Sterilisation Equipment
9. Surgical Image Overlay / Heads Up Display
10. Surgical Instruments
11. Surgical Table
12. Urine Collection System (UCS)
13. Body Bag

Dental Equipment

1. Dental Ancillary Supplies
2. Dental Handheld Instruments
3. Restorative Materials
4. Dental Glove Box
5. Sterilisation Equipment

Clinical Chemistry Analysers

1. Capnograph
2. Complete Blood Count Analyser
3. Centrifuge
4. Optical Microscope and Camera
5. Occult Blood Strip
6. Serum Multiple Analyser (analyses both blood and urine)
7. Slide Staining Apparatus
8. Urine Dipstick

Exercise Countermeasures Equipment

1. Treadmill
2. Cycle Ergometer
3. Multi-Axial Resistive Exerciser
4. Lower Body Negative Pressure (LBNP)

Exercise Countermeasures Monitoring Equipment

1. Blood Pressure Electrocardiograph (BP/ECG)
2. Metabolic Gas Analyser
3. Bone Densitometer
4. Body Mass Measurement Device

ECLSS - Microbiology System

1. Fungal Spore Sampler
2. Incubator
3. Microbial Air Sampler
4. Microbiology Safety Cabinet
5. Optical Microscope & Camera
6. Slide Staining Apparatus (SSA)
7. Surface Sampler Kit (SSK)
8. Water Microbiology Kit

ECLSS - Radiation System

1. Radiation Dosimeters
 2. Extra-Vehicular Charged Particle Directional Spectrophotometer
 3. Intra-Vehicular Charged Particle Directional Spectrophotometer (IV CPDS)
-

4. Tissue Equivalent Proportional Counter (TEPC)

ECLSS - Toxicology System

1. Capnograph
2. Compound Specific Analyser - Combustion Products (CSA-CP)
3. Compound Specific Analyser - Hydrazine (CSA-H)
4. Volatile Organic Analyser (VOA)
5. Personal Air Filter
6. Portable Breathing Apparatus

ECLSS - Water Quality System

1. Ion Selective Electrode Assembly (ISE)
2. Spectrophotometer
3. Total Organic Carbon Analyser (TOC)
4. Water Sampler & Archiver (WS&A)

Contamination Protection Equipment (CPE)

Noise Attenuation Equipment

1. Audiometer
2. Hearing Protectors
3. Noise Dosimeters

Appendix E

ALPHABETICAL DOCC HARDWARE LIST

1. Airway Management System
2. Anaesthesia Apparatus
3. Audiometer
4. Blood Pressure Measurement Device (Sphygmomanometer)
5. Blood Supply
6. Body Bag
7. Body Mass Measurement Device
8. Bone Densitometer
9. Capnograph
10. Centrifuge
11. Complete Blood Count Analyser
12. Compound Specific Analyser - Combustion Products (CSA-CP)
13. Compound Specific Analyser - Hydrazine (CSA-H)
14. Crew Medical Restraint System
15. Cycle Ergometer
16. Defibrillator
17. Dental Ancillary Supplies
18. Dental Glove Box
19. Dental Handheld Instruments
20. Digital Stethoscope
21. Electrocardiograph (ECG)
22. Electroencephalograph (EEG)
23. Endoscopic Surgical Kit
24. Extra-Vehicular Charged Particle Directional Spectrophotometer
25. Freezer
26. Fungal Spore Sampler
27. Hearing Protectors
28. Incubator

- 29.Intensive Care Unit Equipment
- 30.Intra-Vehicular Charged Particle Directional Spectrophotometer (IV CPDS)
- 31.Intravenous (IV) Fluids
- 32.Intravenous Pump
- 33.Ion Selective Electrode Assembly (ISE)
- 34.Laptop Computer
- 35.Lower Body Negative Pressure (LBNP)
- 36.Metabolic Gas Analyser (MGA)
- 37.Microbial Air Sampler
- 38.Microbiology Safety Cabinet
- 39.Multi-Axial Resistive Exerciser
- 40.Noise Dosimeters
- 41.Occult Blood Strip
- 42.Ophthalmoscope
- 43.Optical Microscope and Camera
- 44.Otoscope
- 45.Oximeter
- 46.Personal Air Filter
- 47.Pharmaceuticals & Supplies
- 48.Portable Breathing Apparatus
- 49.Radiation Dosimeters
- 50.Refrigerator
- 51.Restorative Materials
- 52.Serum Multiple Analyser (analyses both blood and urine)
- 53.Sharp Trash Container
- 54.Slide Staining Apparatus
- 55.Slide Staining Apparatus (SSA)
- 56.Soft Trash Container
- 57.Software
- 58.Spectrophotometer
- 59.Standard Diagnostic Tools
- 60.Sterilisation Equipment
- 61.Surface Sampler Kit (SSK)
- 62.Surgical Glove Box
- 63.Surgical Image Overlay / Heads Up Display
- 64.Surgical Instruments

- 65.Surgical Table
- 66.Temperature Probe
- 67.Tissue Equivalent Proportional Counter (TEPC)
- 68.Total Organic Carbon Analyser (TOC)
- 69.Treadmill
- 70.Ultra-sound Device (2-Dimensional Echograph)
- 71.Urine Collection System (UCS)
- 72.Urine Dipstick
- 73.Ventilator
- 74.Video Monitors
- 75.Volatile Organic Analyser (VOA)
- 76.Water Microbiology Kit
- 77.Water Sampler & Archiver (WS&A)
- 78.X-ray Device

Appendix F

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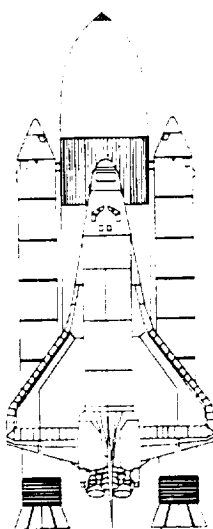
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Appendix G

TRANSPORTATION VEHICLES TO LOW EARTH ORBIT

G.1. Existing and Future Vehicles

The following information is a summary of the different vehicles and it provides complete details about the existing and future transportation systems.

Space Shuttle	
<u>Payload :</u> type : Crew / Cargo maximum capabilities : 5 to 7 crew Payload bay diameter : 4.7 m Payload bay length : 18.6 m Payload mass : 17 100 kg (to space station)	
<u>Flight rate :</u> 8 / year nominal (incl. all missions) 12 / year maximum (incl. all missions)	
<u>Cost :</u> 7.6 k\$/kg for commercial users or 14.32 k\$/kg (total budget divided by flight rate divided by maximum mass)	

X-33

Payload :

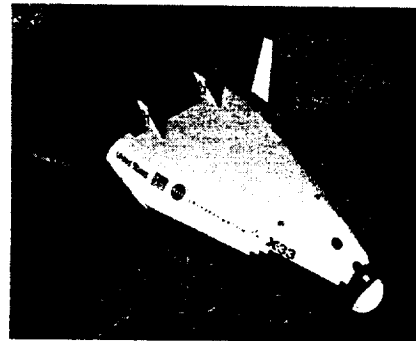
type : Crew / Cargo
maximum capabilities: 5 crew (estimated)
Payload capabilities: as per Space Shuttle

Flight rate : (estimated)

8 / year nominal (incl. all missions)
12 / year maximum (incl. all missions)

Cost :

2.0-4.0 k\$/kg (estimated)



Energia / Buran

Payload :

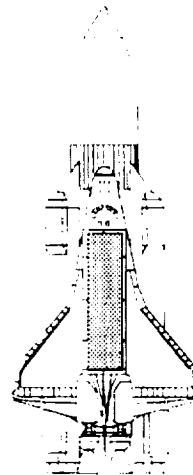
type : Crew / Cargo
maximum capabilities : 2 to 10 crew
Payload bay diameter : 4.7 m
Payload bay length : 18.0 m
Payload mass : 24 000 kg (to space station)

Flight rate :

Not available any more

Cost :

unknown



Soyuz TM

Payload :

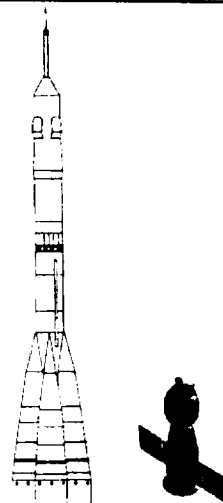
type : Crew / Cargo
maximum capabilities: max. 3 p. up/down
Soyuz TM diameter : 2.7 m
Soyuz TM length : 7 m
Soyuz TM loaded mass : 7 100 kg
(to space station)

Flight rate :

18 per year for manned or unmanned
missions

Cost :

unknown



Soyuz & Progress

Payload :

type : Cargo

maximum capabilities: Unmanned
resupply and logistic

Progress diameter : 2.7 m

Progress length : 7 m

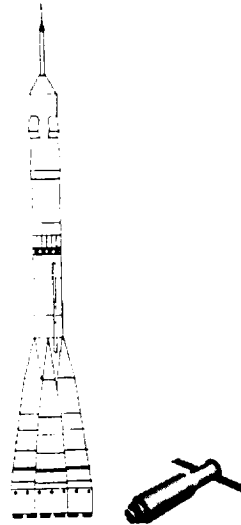
Progress loaded mass : 7 200 kg (to ISS)

Flight rate :

18 per year for manned or unmanned
missions

Cost :

unknown



Ariane 5 & ATV

Payload :

type : Cargo

ATV diameter : 3.9 m (estimated)

ATV length : 17 m (estimated)

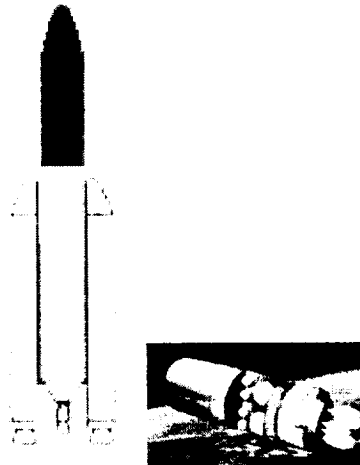
ATV loaded mass : 9 000 kg (to ISS)

Flight rate :

0.66 per year to space station

Cost :

28 k\$/kg (estimated)



H2 & HTV

Payload :

type : Cargo

maximum capabilities:

HTV diameter : 4.4 m

HTV length : 8 m

HTV loaded mass : 6 000 kg (to ISS)

Flight rate :

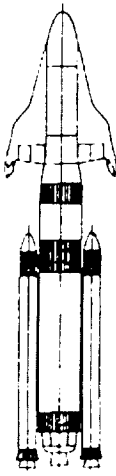
1 per year (estimated)

Cost :

unknown

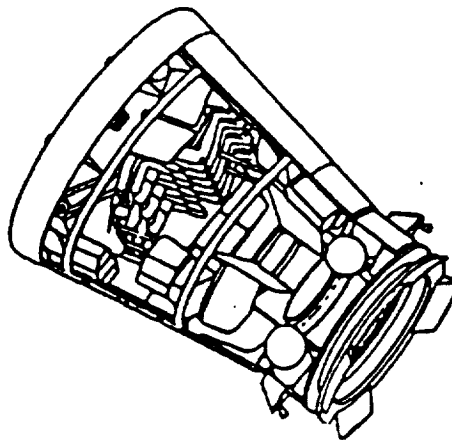


CRV	
<u>Payload :</u> type : Crew	
<u>Flight rate :</u> 1 or 2 available permanently attached to the space station	
<u>Cost :</u> unknown	

HOPE	
<u>Payload :</u> type : Cargo HOPE length: 18 m HOPE width: 10 m HOPE diameter: 3 m Total Weight: 20 000 kg Carrying capacity: 3 000 kg	
<u>Flight rate :</u> unknown	
<u>Cost :</u> unknown	

G.2. Crew rescue vehicles

G.2.1. Escape Vehicle EV-0

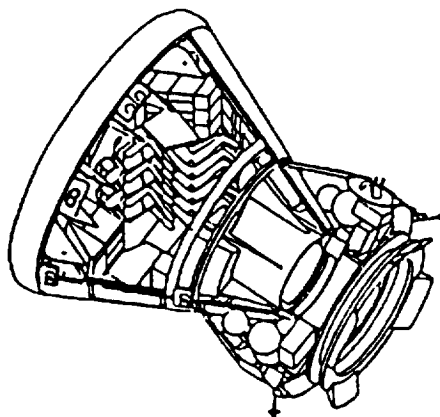


Escape Vehicle EV-0

EV-0 mass budgets (kg)		
Subsystem	OSM	RC
Structural/Mech.	500	502
TCS	20	86
ECLSS		32
EPS	20	185
DHS	5	28
COMS		10
GNC		35
PROP	68	12
Crew system		259
TPS		157
Landing system		106
MODULE DRY MASS	613	1412
Consumables		12
Propellant	191	5
Crew		300
MODULE WET MASS	804	1729
+ 15% margin	925	1988
EV OVERALL MASS	2913	

G.2.2. Escape Vehicle EV-1

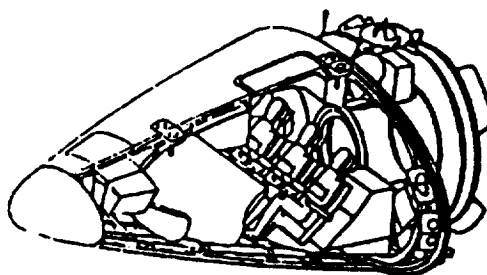
EV-1 mass budgets (kg)		
Subsystem	OSM	RC
Structural/Mech.	574	687
TCS	21	106
ECLSS		50
EPS	328	128
DHS	5	30
COMS	118	17
GNC	13	35
PROP	122	47
Crew system		273
TPS		249
Landing system		183
MODULE DRY MASS	1181	1805
Consumables		45
Propellant	292	11
Crew		300
MODULE WET MASS	1473	2161
+ 15% margin	1694	2485
EV OVERALL MASS	4179	



Escape Vehicle EV-1

G.2.3. Escape Vehicle EV-2

EV-2 mass budgets (kg)		
Subsystem	OSM	RC
Structural/Mech.	650	1430
TCS	21	130
ECLSS		50
EPS	388	138
DHS	5	40
COMS	118	21
GNC	13	55
PROP	122	50
Crew system		280
TPS		400
Landing system		400
MODULE DRY MASS	1317	2994
Consumables		50
Propellant	340	30
Crew		300
MODULE WET MASS	1657	3374
+ 15% margin	1905	3880
EV OVERALL MASS	5785	



Escape Vehicle EV-2

G.2.4. Soyuz as an Escape Vehicle

- three crew members
- length: 7.94 m
- max. diameter: 2.72 m
- volume (re-entry capsule): 3.8 m³
- weight (orbiting): 6.8 metric tons
- weight (landing): 2.8 metric tons
- autonomy: 3 days

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Appendix H

DOOC HARDWARE LIST FOR MARS

The following tables give a survey which medical components will be arranged together for the Mars application (see Chapter 8.4).

☐ Medical Bed Unit

MEDICAL BED UNIT	
1	Physical structure to restraint a patient (deployable from the floor and electrically isolated [defibrillator!])
2	Small ECG with 15x10 cm monitor
3	x-ray digital imaging system (radiation source on an arm mounted at the ceiling)
4	Pulse and Blood Pressure Measurement Device
5	Intravenous Pump
6	Temperature Probe
7	Oximeter
8	Radiation Dosimeters
9	Urine Collection System (UCS)
10	Surgical Glove Box (stored in the floor)
11	Dental Glove Box (stored in the floor)

☐ Cabin Environment Monitoring Unit

CABIN ENVIRONMENT MONITORING UNIT	
1	Compound Specific Analyser - Combustion Products (CSA-CP)
2	Compound Specific Analyser - Hydrazine (CSA-H)
3	Microbial Air Sampler
4	Volatile Organic Analyser (VOA)
5	Fungal Spore Sampler
6	Intra-Vehicular Charged Particle Directional Spectrophotometer (IV CPDS)
7	Noise Dosimeters

☐ Monitoring, respiration and medical equipment unit

MONITORING, RESPIRATION AND MEDICAL EQUIPMENT UNIT	
1	Standard Diagnostic Tools
2	Digital Stethoscope
3	Ophthalmoscope (eyes)
4	Otoscope (ears)
5	Audiometer
6	Intensive Care Unit Equipment
7	Airway Management System
8	Ventilator
9	Personal Air Filter
10	Metabolic Gas Analyser (MGA)
11	Anaesthesia Apparatus
12	Electrocardiograph (ECG)
13	Electroencephalograph (EEG)
14	Sterilisation Equipment
15	Surgical Instruments
16	Endoscopic Surgical Kit
17	Surgical Image Overlay / Heads Up Display
18	Ultra-sound Device (2-Dimensional Echograph)
19	Capnograph
20	Dental Handheld Instruments
21	Dental Ancillary Supplies
22	Urine Dipstick
23	Defibrillator

☐ Countermeasure Unit

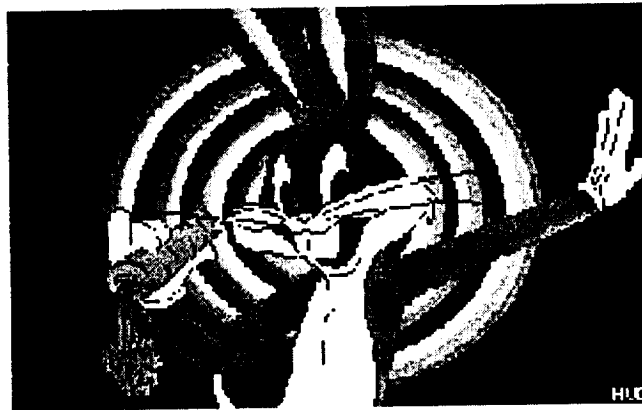
COUNTERMEASURE UNIT	
1	Body Mass Measurement Device
2	Bone Densitometer
3	Cycle Ergometer
4	Treadmill
5	Multi-Axial Resistive Exerciser
6	Lower Body Negative Pressure (LBNP)

☐ Medical Laboratory Unit

MEDICAL LABORATORY UNIT	
1	Microbiology Safety Cabinet
2	Centrifuge
3	Complete Blood Count Analyser
4	Freezer
5	Incubator
6	Optical Microscope and Camera
7	Slide Staining Apparatus
8	Slide Staining Apparatus (SSA)
9	Serum Multiple Analyser (analyses both blood and urine)
10	Tissue Equivalent Proportional Counter (TEPC)
11	Soft Trash Container
12	Sharp Trash Container
13	Occult Blood Strip
14	Urine Dipstick
15	Surface Sampler Kit (SSK)
16	Water Microbiology Kit
17	Water Sampler & Archiver (WS&A)
18	Spectrophotometer - water
19	Total Organic Carbon Analyser (TOC) - water
20	Ion Selective Electrode Assembly (ISE) - water
21	Computer System
22	Portable Breathing Apparatus

☐ Storage Unit

STORAGE UNIT	
1	Pharmaceuticals & Supplies
2	Refrigerator
3	Blood Supply
4	Intravenous (IV) Fluids
5	Body Bag
6	Spare parts and spare equipment for redundancy



"What's up DOCC?"

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